THE RELATION OF WATER CONTENT AND CONSISTENCY OF MIX TO THE PROPERTIES OF CONCRETE

BY

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I. INTRODUCTION

1. Preliminary .- The design of concrete mixtures has been more or less a matter of approximation. It has not been possible with any given materials to determine readily what proportions should be used to obtain a concrete of predetermined strength. In order to use the materials economically, it is desirable to be able to so design concrete mixtures. A study of the properties of concrete has been carried on for some time by the department of Theoretical and Applied Mechanics. During December, 1920, a new set of tests was laid out, following a new method of attack, and a part of the work was assigned for two theses. The relation of water content and consistency of mix to the properties of concrete will be considered in this thesis. Mr. M. C. Nichols' thesis deals with the relation of fine aggregate to the properties of concrete.

2. Scope of Investigations.- This thesis deals with the concretes made from three artificially graded sands. With a given sand the mix was varied by changing the amounts of cement, sand, gravel, and water used. The mortar data and the description of ten natural sands are also given. The data for the concretes made from these natural sands can be found in the thesis by Mr. M. C. Nichols on "Relation of Fine Aggregate to the Properties of Concrete". They were mixed with an amount of water which gave the minimum volume of concrete. The natural sands had one standard of water content.

3. Acknowledgments.- The work was carried on under the direction of Professor A. N. Talbot, Mr. F. E. Richart and

Mr. H. J. Gilkey, both of the Engineering Experiment Station, gave considerable time to the work of the investigation. Mr. M. C. Nichols, graduate student in Theoretical and Applied Mechanics, worked on his thesis at the same time.

II. ANALYSIS AND THEORY

4. Notation and Definitions.-

c = absolute volume of cement per unit volume of concrete.

c' = absolute volume of cement in the mix used.

a = absolute volume of sand per unit volume of concrete

a' = absolute volume of sand in the mix used.

b = absolute volume of coarse aggregate per unit volume of concrete.

b' = absolute volume of coarse aggregate in the mix used.

v = per cent of voids in the concrete mix.

v_m = per cent of voids in the mortar mix.

$1 - b$ = volume of mortar in concrete.

$\frac{a + c}{1-v_m}$ = Volume of mortar.

w_{mo} = absolute volume of water per unit volume of mortar at basic water content.

w_m = absolute volume of water per unit volume of mortar.

$\frac{w_m}{w_{mo}}$ = Water Content Ratio.

W_{cx} = absolute volume of water per unit volume of concrete.

w_c = absolute volume of water per unit volume of concrete after absorption of water by the aggregate has taken place

$\frac{w_c}{c}$ = Water-cement Ratio relation.

$\frac{w_c}{v}$ = Per cent of voids filled with water.

$\frac{w'}{w_{mo}}$ = Ratio of water used in the mix to the water in the mix at basic water content. This value was only used on the curves as a symbol.

The Basic Water Content of a mortar is that amount of water which will give the minimum voids in the mortar.

Water Content Ratio is the ratio of the volume of water which was used per unit volume of mortar to the volume of water per volume of mortar at basic water content.

Water Cement Ratio is the ratio of volume of water per unit volume concrete to the absolute volume of the cement per unit volume of concrete.

Cement-Space Ratio is the ratio of the absolute volume of the cement to the sum of the volume ofthe voids and the absolute volume of the cement.

5. Theory of Design of Mixes.- The method of design, upon which the work in these theses is based, was developed by Professor A. N. Talbot. It commences with a study of the mortar used in the concrete. It is assumed that the ratio of the absolute volume of the sand to the absolute volume of the cement is some function of the voids in the mortar.

$$\frac{a}{c} = \theta\,(V_m) \qquad (1)$$

With the values of sand, cement, and voids used in the mortar, the properties of the mortar will be known. The amount of water used will be taken care of in the voids since this value will be determined by experiment using different amounts of water. The volume of the mortar will equal the sum of the absolute volumes of sand and cement divided by the density or

$$\frac{a + c}{1 - V_m} = \text{Vol. of mortar}$$

With the amounts of coarse aggregate ordinarily used in concrete, the volume of the concrete will equal the bulk of the mortar plus the absolute volume of the coarse aggregate or

$$\frac{a + c}{1 - v_m} + b = 1 \qquad (2)$$

also the density will equal the sum of absolute volumes of the sand, cement, and coarse aggregate or

$$a + b + c = d \qquad (3)$$

The strength of the resulting concrete may be a function of some property of the concrete, then

$$S = \phi\,(v, c, a, b) \qquad (4)$$

It is seen that there are seven unknowns and only four relations.

The two arbitrary functions θ and ϕ are determined by experiment while the third unknown may be varied to suit the particular condition. It is not unreasonable to have more unknowns than equations since the strength of the concrete may be a function of the density using the same amount of cement or it may be a function of the cement using the same density and possibly some other relations. The method given assumed that the function θ would be determined by experiment for the sand used. It is undesirable, however, to determine the function ϕ by experiment for a particular sand because it would require considerable equipment and time. It is possible that such a function will be found which will apply to all concretes It is desirable that ϕ be as simple a relation as possible. In this thesis an attempt will be made to show some of these relations.

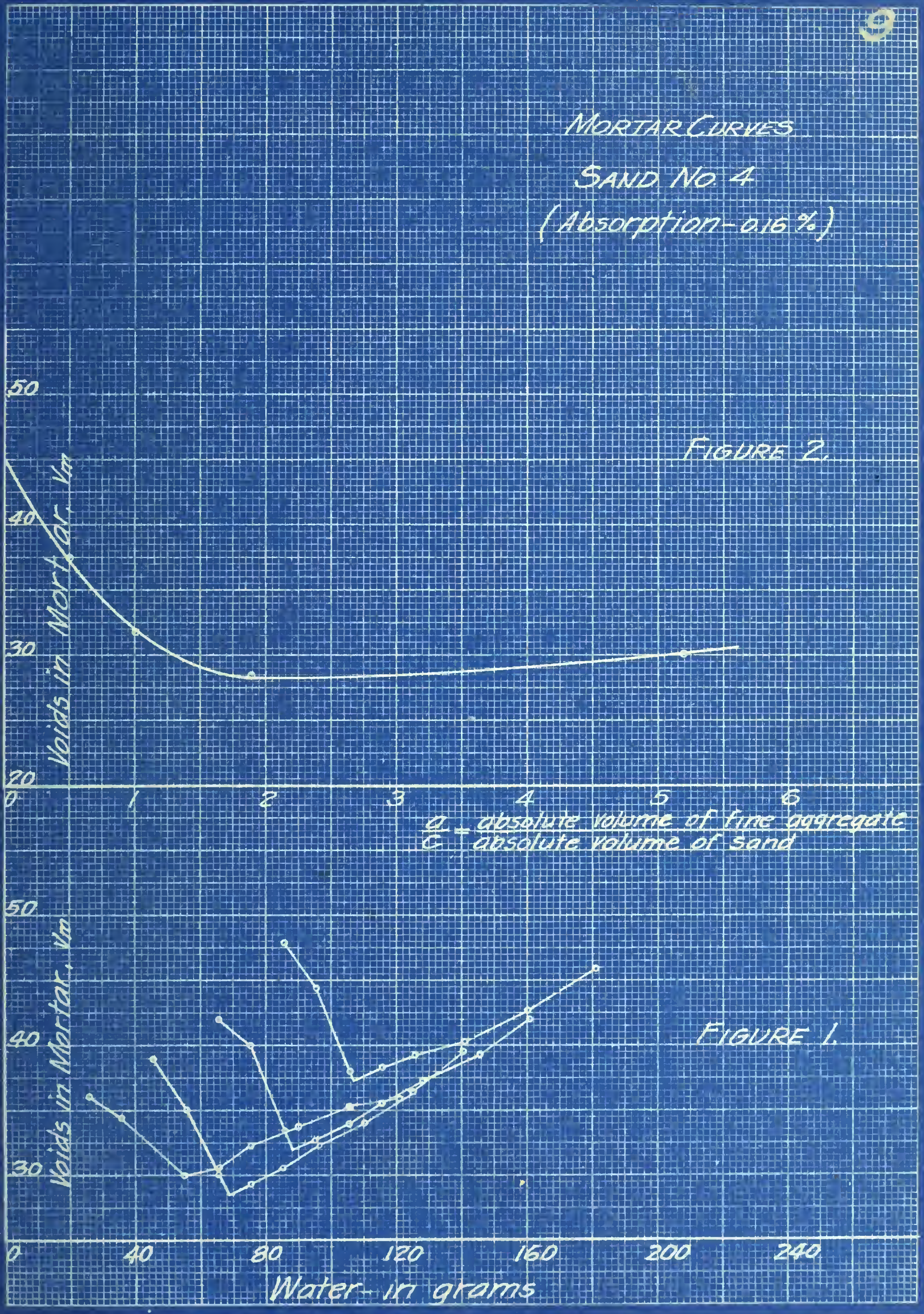
This method does not consider directly the question of workability. This will undoubtedly enter in the amounts of cement, coarse aggregate, and water used and give one more equation reducing the unknown to two. The values obtained from the use of the formulas must be considered to make sure that they are reasonable. The absolute volume of the cement might vary from .06 to .15 cu. ft. per cu. ft. of concrete. The absolute volume of the coarse aggregate might have a value around .50 cu. ft. per cu. ft. of concrete for a maximum value, depending upon the materials used. The more workable mixes are obtained with the larger values of cement and smaller values of coarse material and with wet mixes. The water content to be used will depend upon the conditions of placing the concrete and is independent of the computations of the quantities in the mix if the mortar curve for this water content

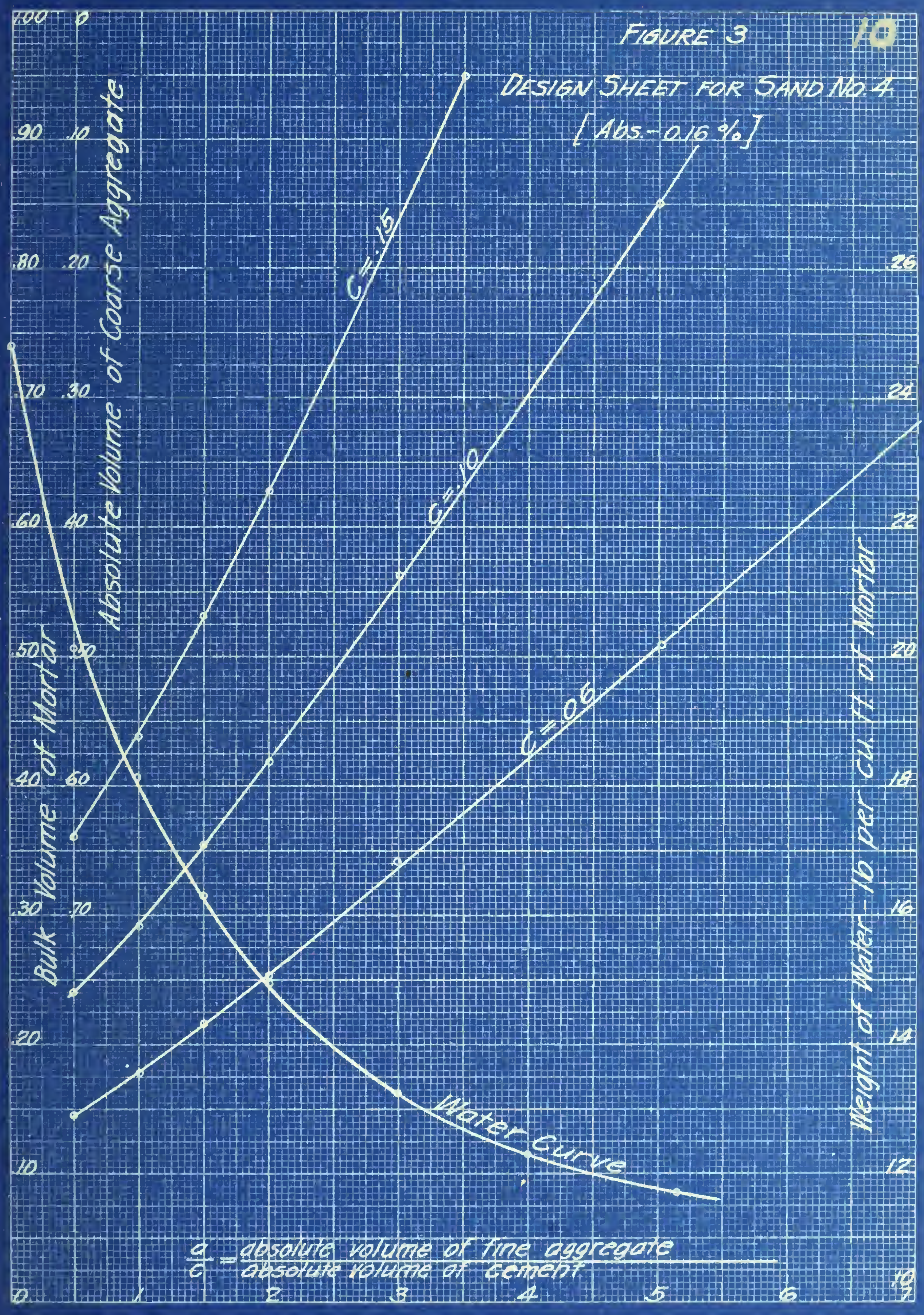
is used in the calculations.

6. Voids-Mortar Tests.- In order to find the properties of a mortar used in a concrete mix it is necessary to make a test with the mortar. Knowing the voids in the mortar with different amounts of cement and water will determine the properties which are desired. To make up a mortar a value was assumed for $(a + c)$ and $\frac{a}{c}$ which determined the amount of sand and cement to use. To get the weights of the sand and cement to use, the specific gravity of the sand and cement must be known. To get the bulk volume of the materials the weights per unit volume would have to be known. For this thesis the proportioning was done by weights. Generally $a + c$ was taken as 200 cubic centimeters and $\frac{a}{c}$ as 1, 2, 3 1/2, and 6. With a given mix the water was varied so that the mortar varied from a very dry mix to a very wet one. From these data curves are plotted showing the relation between the voids and water in the mortar. The function ϕ is also determined by experiment but it is desirable to obtain a function that will apply to all concretes. The function is determined by plotting past tests and using the function which actually fits all of the cases. This value is the only one to be questioned in the method of design since the success of the method depends upon the closeness with which this function is determined. As stated before one of the objects of this thesis is to check up on this relation so it was not used in the designing of the mixes. In its place one of the other unknowns had to be arbitrarily fixed. The method that follows was used to design the mixtures.

7. <u>Design of Concrete Mixes</u>.- In designing the mixes to be used it was thought best to assume a value for b and c and to compute the amount of sand necessary. The method used to do this was devised by Mr. Nichols and Mr. Richart. From the mortar voids data, curves were plotted for the bulk of the mortar with the values of c to be used in the concrete, against values of $\frac{a}{c}$. The values of cement (c) used were .06, .10, and .15. Since b equals one minus the bulk volume of mortar, this graph gave an easy method for determining the $\frac{a}{c}$ necessary and from that the value of a to be used. On this same sheet was plotted the weight of water, at the basic water content, per cu. ft. of mortar against the values of $\frac{a}{c}$. This value was taken from the void mortar curves Absorption by the aggregate was not allowed for in this curve. For an example a mix which was used will be given, which will show the method of design. Figure 1 was plotted from the mortar data for the sand used. Figure 2 was obtained from Figure 1. Figure 3 was obtained from Figure 2. The water curve, for basic water content, in Figure 3 was obtained from Figure 1.

Given sand No.4, design a mix for c = .15 and b = .35 at basic water content. The specific gravity of the sand is 2.63 and the absorption 0.16 per cent by weight. The coarse aggregate is the same as that used in this thesis. From Figure 3 for c = .15 and b = .35, it is found necessary to use an $\frac{a}{c}$ of 2.1 which gives for a, 0.315. The volume of the mold used was about 1/5 of a cubic foot. All mixes at basic water content were designed to make 2/9 of a cubic foot of concrete. The weight of the materials to use were determined from the equation


9
MORTAR CURVES
SAND NO. 4
(Absorption-0.16%)
FIGURE 2.
Voids in Mortar, Vm
50
40
30
20
0
1
2
3
4
5
6
a = absolute volume of fine aggregate
C = absolute volume of sand
FIGURE 1.
Voids in Mortar, Vm
50
40
30
0
40
80
120
160
200
240
Water-in grams


10
FIGURE 3
DESIGN SHEET FOR SAND No. 4
[Abs.-0.16 %]
C=.15
C=.10
C=.06
Water Curve
Bulk Volume of Mortar
Absolute Volume of Coarse Aggregate
Weight of Water - lb per cu. ft. of Mortar
a/c = absolute volume of fine aggregate / absolute volume of cement
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
0
.10
.20
.30
.40
.50
.60
.70
1
2
3
4
5
6
7
26
24
22
20
18
16
14
12
10

$$w = \text{sp.gr.} \times 62.4 \times \frac{2}{9} \times (a,\ b,\ \text{or } c)$$

which gives the following weights:

Cement = 6.45 pounds

Sand = 11.50 "

Gravel = 13.15 "

From the water curve, it is found that the mortar requires 14.7 pounds of water per cu. ft. of mortar. The mortar in this mix would then require

$$\text{Water} = 14.7 \times 0.65 \times \frac{2}{9} = 2.12 \text{ pounds.}$$

Absorption of water by the sand will require 0.02 pounds and by the coarse aggregate 0.13 pounds making the total amount of water necessary to use 2.27 pounds.

It is important to note that the water contents above the basic water content as used in this thesis were not used as explained in the theory of design. Instead, 120, 140, and 160 per cent of the water required by the mortar were added to the mix as figured for the basic water content. The absorption of the fine and coarse aggregate was added to this quantity to get the total amount of water required. By adding water in this manner, the quantities of materials in a unit volume of concrete were not known, but from the amount of water added, the volume of the resulting mix and the quantities of material in it could be determined.

III. MATERIALS

8. Methods Used to Determine Properties.- Before giving the properties of the materials used, the method of determining these properties will be described as follows:

a. Weight per cubic foot

b. Sieve Analysis

c. Specific gravity

d. Absorption

a. Weight Per Cubic Foot.- The weight per cubic foot was obtained by filling a steel mold of known volume and weighing its contents. The mold was approximately 8 3/16 inches in diameter and 6 9/16 inches high. The volume of the mold determined from careful measurements was .202 cu. ft. The mold was filled in three layers. Each layer was tamped in with about thirty strokes of a wooden tamp about one and one-half inches square. This value was not used in any calculations. It is given only as information on the sand.

The value given is the average of three trials.

b. Sieve Analysis.- Before making the sieve analysis of the natural sands, the material was placed in an oven for one day where the temperature was 212 degrees Fahrenheit. The material for the artificially graded sands was placed on the steam racks for a day before separating.

The material for the three artificially graded sands was separated into desired sizes with a Combs Gyratory Riddle which used eighteen inch screens. The material was then remixed in the desired proportions. The mechanical analysis of the natural sands

was made on a Ro-Tap machine using eight inch screens. The sample of 500 grams was placed in the machine and run for fifteen minutes The sample was then weighed up. The sieve analysis of the artificially graded sands was also run in thismanner. The values given in the table are these values rather than the ones from which the mix was made up. This put the natural and artificially graded sands on the same basis. The sample of the natural sands was taken at the time the sand was remixed. A sampler was used.

c. Specific Gravity.- The Le Chatelier flask was used to determine the specific gravity of the sands. The standard method of procedure as given by the American Society for Testing Materials for testing cement was followed except that water was substituted for kerosene and a 54 gram sample was used.

The specific gravity of the coarse aggregate was determined from the formula

$$S = \frac{w\ d}{(wd + a) - w}$$

in which

S = apparent specific gravity

wd= dry weight of stone in air

w = weight of stone suspended in water.

a = total weight of water absorbed.

A sample of about 2 1/2 kilograms dried to a constant weight was used. A wire bucket and metric scales which are a part of the regular equipment of the laboratory were used.

The specific gravity given in the table is the result of at

least three trials.

d. Absorption.- The test for absorption as given in the preprint for "Recommended Practice for Making Compression Tests of Concrete" by the American Society for Testing Materials was followed. This preprint was oublished in the Proceedings of the American Society for Testing Materials Committee Reports, 1920, p. 294 as "Outline of Compression Test of Concrete for Investigation of Properties of Concrete Mixtures."

The values given are the average of at least three trials and are by weight.

9. Materials.-

a. Cement.- Universal Portland Cement was used. The department had had this cement for 4 1/2 years. Before using it was screened over a No. 28 screen. It had a specific gravity of 3.10 and weighed 94 pounds per cubic foot. The cement was tested by the Department of Highway Engineering. The tests of the concrete cylinders also showed good strength as compared with the series 2G of 1919 so there was no reason to question the quality of the cement.

The results of the tension tests of 1:3 mortar by weight using standard Ottawa sand, are given below. The values given are the average of three tests made from four samples.

	7 day	28 day
	170	270
	155	285
	160	260
	215	315
Average strength	175	282

The cement passed the soundness test . The per cent of water at normal consistency was 24.

b. <u>Sand.</u>- The colormetric test was made on all the sands used and they were found to pass satisfactorily with nearly clear solution.

For the three artificially graded sands, Attica sand which the department had on hand was used. They were made up in batches of three hundred pounds each. Each batch was mixed in a large pan and turned with shovels till it was of a uniform mixture. It was then placed in a can for use. The properties of the Attica sands are given in a table. (see page 18)

The natural sands used were sent to the department by Professor D. A. Abrams of Lewis Institute, Chicago. Twenty-two sands were received. Ten of them are described and the mortar tests given in this thesis. The others may be found in the thesis on, "The Relation of Fine Aggregate to the Properties of Concrete", by M. C. Nichols. As received sand No. 9 contained considerable coarse material. To make this sand comparable with the other sands it was screened over a No. 4 screen. The material retained on this screen was not used.

Sand No. 4 came from the Kaw River at Kansas City. It is mostly quartz with a little granite. It does not glisten, is dull yellow in color, and the particles are very uniformly round.

Sand No. 9 is limestone screenings from Chicago, Illinois. It is nearly white in color. The particles are very angular. 94 per cent of this sand passed the No. 4 screen and was retained on the No. 8 screen.

Sand No. 10 is a Dune sand from Gary, Indiana. The main part is quartz, a little granite, some signs of vegetation, and a fine black substance. It glistens in the sun and is ordinary sand color.

Sand No. 12 is a crushed granite from Berlin, Wisconsin. It is dark red. The larger particles are very angular and rough. The finer particles are whiter and resemble dust.

Sand No. 13 is Platte River gravel from Fremont, Nebraska. The sand is nearly all quartz . The gravel is a granite. It is dull grey in color. The larger particles are very angular while the small ones are nearly round.

Sand No. 14 is a glass sand from Mapleton, Pennsylvania. It is nearly white in color. The particles are round but the surfaces seemed to be rough.

Sand No. 15 is a slag from Lorain, Ohio. The particles are very angular and porous. It is light grey in color.

Sand No. 17 is a sea sand from Atlantic City, New Jersey

The major part is a quartz. There is also some granite and a considerable quantity of a fine black powder. It glistens in the sun.

Sand No. 20 came from Elgin, Illinois. It is trap rock with fairly round grains. It is washed. The color is dull yellow.

Sand No. 22 is the same as sand No. 20 except, that it is not washed. This sand contained enough clay to make it very visible.

c. Gravel.- The gravel used came from Attica, Indiana and had been in the laboratory for some time. It was screened out into sizes ordinarily kept on hand in the concrete laboratory. It was remixed in the ratio of 60 per cent of 3/8 to 3/4 in. and 40 per cent of 3/4 to 1 inch size. The mixed material as used had a specific gravity of 2.71, voids of 39.3 per cent and weighed 102.5 pounds per cu. ft. The absorption was 1.0 per cent by weight.

d. Water.- Tap water from the University water supply was used. There was no reason to question the use of this water for making concrete.

10. Mortar Tests.- These tests followed the method explained in the Analysis and Theory. The details of the methods of making the tests are given in the thesis on, "The Relation of the Fine Aggregate to the Properties of Concrete" by M. C.Nichols.

PROPERTIES OF SAND USED

No.	Abrams 1st No.	Sand	Location	Properties: Wt. per cu.ft.	Properties: Spec. Grav.	Properties: Absorption
4	3785	River Sand	Kaw River K.C, Mo.	109.5	2.63	0.16
9	3967	Limestone Screenings	Chicago, Illinois	96.9	2.77	0.16
10	4014	Dune Sand	Gary, Indiana	101.1	2.68	0.80
12	4081	Crushed Granite	Berlin, Wisconsin	114.1	2.61	0.20
13	4147	Platte River Gravel	Fremont, Nebraska	121.0	2.63	0.10
14	4189	Glass Sand	Mapleton, Pa.	95.1	2.64	0.40
15	4238	Slag	Lorain, Ohio	91.3	2.64	0.94
17	4598	Sea Sand	Atlantic City, N.J.	107.4	2.75	0.84
20	5067	Sand Washed	Elgin, Illinois	114.0	2.72	0.52
22	5198	Sand Unwashed	Elgin, Illinois	116.0	2.72	0.36
26		Neat Cement		94.0	3.10	
31		Artificial Grading	Attica, Indiana	116.7	2.69	1.12
32		Artificial Grading	Attica, Indiana	108.5	2.69	1.12
36		Artificial Grading	Attica, Indiana	103.7	2.69	1.12

SIEVE ANALYSIS

PER CENT PASSING SIEVE NUMBER

No.	200	150	100	48	28	14	8	4	3/8"
4			0.3	3.3	39.5	75.4	91.3	98.3	100
9			2.6	2.9	3.2	3.3	5.8	100	
10	0.3	0.5	6.1	94.6	99.6	100			
12			14.8	20.9	28.0	39.1	60.9	95.8	
13			2.7	18.7	41.6	56.8	70.9	87.9	97.6
14	0.5	0.7	2.6	31.8	93.2	99.1			
15			8.6	15.0	24.4	34.4	54.7	92.7	
17	0.2	2.2	9.3	95.0					
20			1.5	11.6	50.6	71.1	85.7	98.3	
22			1.4	6.5	36.7	57.4	92.6	94.7	
26									
31			3.3	14.2	28.9	55.0	77.8	99.0	
32	2.7	3.5	6.6	42.8	77.7	99.1			
36	0	0	0.4	0.6	2.9	63.0	87.8	100	

Tyler Standard Sieves Used.

IV. METHODS

11. Concrete.- The party making the concrete specimens had never less than five men. The division of labor was as follows, one man recording, two men mixing, one man weighing out materials, and one man keeping pans, flow table, and tables clean.

a. Selection of Materials.- The artificially graded sands were made up and stored in cans. The sand was taken out as needed with a hand scoop. This method seemed to give a fair sample. The two sacks of each natural sand were emptied into a large pan and thoroughly mixed. They were then resacked until used. When using a sand, a bucket was filled with the sand and it was weighed out from the bucket as needed.

The cement was screened and then stored in large cans from which it was taken to make the mixes.

The coarse aggregate was separated and stored in large cans. The quantities for the mix were taken from these cans. This seemed better than to mix up the materials in large batches because of the possibility of separation of the material of different sizes.

b. Weighing out of Materials.- Each mix had its own data sheet. From this sheet, a card was made out giving the weights of the various materials used in the mix. This card was kept with the data sheet which reduced the chances of error in getting the wrong weights in the mix. One man did nothing but weigh out materials. The cement was weighed out first, then the sum of the cement plus the sand was set off and the sand added. This was then placed in the dry pan. Next the coarse

material was weighed out, the amount of 3/8 inch to 3/4 inch first and then the 3/4 inch to 1 inch added to it. This was placed in the dry pan with the sand and cement and thoroughly mixed.

c. Mixing of Materials.- Before placing the materials in the wet pan, the pan was dampened with a wet cloth. No free water was left in the pan. The dry materials were then emptied into the wet pan and so arranged as to form a hollow place in the center. The predetermined amount of water was added to the mix. A large burette, calibrated in pounds was used to measure out the water. A tube was attached to it so that the water could be run into the hollow place found in the pile of the materials. The recorders attempted to check the reading of the water admitted each time in order to eliminate error. The dry material was worked in until the water was taken up. The batch was then mixed until it was a uniform mixture throughout. This generally required from one to three minutes depending upon the amount of water used and the particular materials.

d. Flow Table Test.- After the batch was mixed, it was placed on the flow table for the flow table test. This test is the one developed by Mr. G. M. Williams while he was with the Bureau of Standards. The mold used was eleven inches in diameter at the bottom and six inches at the top. Its height was about six inches. The height was used which gave a volume of 0.200 cu. ft. The concrete was placed in the mold with a small hand scoop and tamped in with a one and one-half inch square wooden tamp. The concrete was worked into the mold as well as possible,

but due to the shape of the mold there were always more air voids than would be found in the cylinder made of the same mix. This undoubtedly affected the flow but it entered into all mixes so that the results might be used for comparison without serious error. The mold was removed and the table given fifteen one-half inch drops. The time required to give the fifteen drops varied from eight to twelve seconds. The increase in diameter of the mass at the base was measured in two or three directions depending upon the condition of the concrete after the drops. The loose rocks, which fell down on the table from the top of the mold, were removed and the diameter measured to the edge of the mortar. In some cases where the mix was very wet it was not placed on the flow table. In other cases of wet mixes it was placed on the flow table but was given ten drops instead of fifteen. This data is not reported in this thesis. The original data is filed in the permanent records of the department.

The flow table and method used was similar to that described by G. M. Williams in Engineering News-Record, June 12, 1919, page 1143.

e. Making of Specimens.- After taking the material off the flow table it was remixed and placed in a 6 x 12 inch cylinder mold. The molds used were those in the concrete laboratory. The mold number, the diameter, height, and volume of the mold were painted on the molds. The record of the cylinders was kept by means of these data until the cylinder number could be painted on the cylinder, which was done when the mold was removed. This

record was also used to get the cylinders out for testing. The mold together with its base plate were weighed before it was filled. A three to four inch layer of concrete was placed in the mold and rodded with a one-half inch pointed steel rod about thirty times. The outside of the mold was then pounded with a wooden mallet till water flushed to the surface of the contents. Another layer was then added and the same process repeated. The amount of labor required to fill the mold varied considerably. In a few cases with a dry mix, a large amount of coarse aggregate, and a small amount of cement it took about thirty minutes to fill the mold. Ordinarily it took from four to eight minutes to fill the mold. When it was filled, the top of the concrete was smoothed up with a trowel in order to make the volume of the concrete as nearly equal to the volume of the mold as possible. The reason for this care was that the volume of the concrete was used in later calculations. Mortar on the outside of the mold was then cleaned off and the filled mold weighed. The difference between the weights of the empty mold and the filled one gave the weight of the concrete in the mold. Two workmen, Mr. Slade and Mr. Kirby, made all of these cylinders. In a few cases the batch was so hard to place that both men worked on one cylinder, hammering the sides of the mold and rodding the concrete. Both men had a little experience in the laboratory making test specimens before starting on this series. The closeness with which the companion cylinders checked out seemed to indicate that their work was entirely satisfactory.

f. Care and Storage of Specimens.- After the filled mold was weighed, it was placed on a table for the concrete to harden. At the end of the day on which the cylinders were made, a neat cement cap was placed on each of them to insure a uniform bearing surface in the testing machine. The cylinder was capped by placing a small amount of neat cement paste, made just stiff enough to stand up under its own weight, on top of the cylinder. This cement paste was then covered with a piece of waxed paper. A piece of plate glass was placed on this and forced down on the mortar till the glass was bearing uniformly over the surface of the cylinder. The cylinders were allowed to set for at least a couple of hours before the cap was put on in order that the cylinder would not shrink up and break off the cap.

The next morning, before the mold was removed, the cylinder numbers which were obtained from the mold numbers were painted on top of the cylinder. The molds were removed with as much care as possible. Only a few cylinders were broken in handling. A few of the cylinders, which were made at the end of the run on the preceding day, were usually left until later in the day before removing the mold, in order that they might have more time to harden. After the molds were removed, the number of the cylinder was painted on the side of the cylinder in order to be sure that the cylinder would not be lost in case the cap was accidentally knocked off.

The cylinders were then placed in the damp room. The temperature in the room was nearly constant at about seventy degrees. The humidity gage showed a humidity of 100 all of the time. The cylinders were set on the floor of the room. There was no covering. No

water was allowed to drip or run on the specimens. Moisture collected on the cylinders, however. Accompanying photographs will show views of the cylinders in the damp room.

g. Testing of Specimens.- The cylinder, at the age of twenty-seven days, was removed from the damp room to the main laboratory where it was allowed to dry out for one day before being tested. The cylinder was weighed and its diameter and height measured before it was tested at twenty-eight days of age. The 300,000 pound Olsen machine in the concrete laboratory was used for this purpose. The cylinder was set on a machined cast iron bearing block. The extensometer was then placed in position on the cylinder. Another bearing plate was placed on top of the cylinder. A spherical bearing block was placed on this plate and the specimen slid into position in the machine. All possible care was used in placing the specimen in the machine. A crosshead speed of 1/2 inch per minute was used for the testing. The semi-autographic stress strain recorder was used. The maximum load was determined by the drop of the beam.

The gage length of the extensometer used was six inches. The stress strain curves are filed with the original data.

12. Explanation of Diagrams.-

Mortar Data.- This data is given by curves which were plotted from the original data. The following notation was used.

v_m = voids in the mortar

c = absolute volume of cement per unit volume of mortar.

$\frac{c}{v+c}$ = cement-space ratio for mortar.

w_{mo} = volume of water per unit volume of mortar.

All of the above quantities are plotted for basic water content The amount of water absorbed by the sand has been sub tracted from the amount given in the $\frac{a}{c}$ curves. As the curves w_{mo} was obtained from these curves the absorption of water by the sand and not included in the curve. The absorption for each sand is given in a table with the description of the sands.

Concrete Data.- The concrete data is given under the sand number of which the concrete was made. In some cases where it was evident that there had been a mistake made in weighing out the mix the results of that cylinder were omitted from this table. A few cylinders were accidently broken in handling. The measured quantities of materials in these cylinders were omitted also. Diagrams showing per cent of voids filled with water at various water content ratios. These data were plotted from the average values of the concrete data. The per cent of voids filled with water was obtained from the column headed $\frac{wc}{v}$. The water content ratio, $\frac{w_m}{w_{mo}}$.

Diagram showing Change in Strength with Variations in the Water Content Ratios.- The average value of the cylinders made at basic water content was taken as the maximum strength. Where there were no cylinders made at the basic water content the average of the cylinders with the lowest water content ratio was taken as the maximum value. This spread the curves out and also changed the slope of that set. It was thought best to plot them in this way rather than assume a value for the strength of the concrete at basic water content.

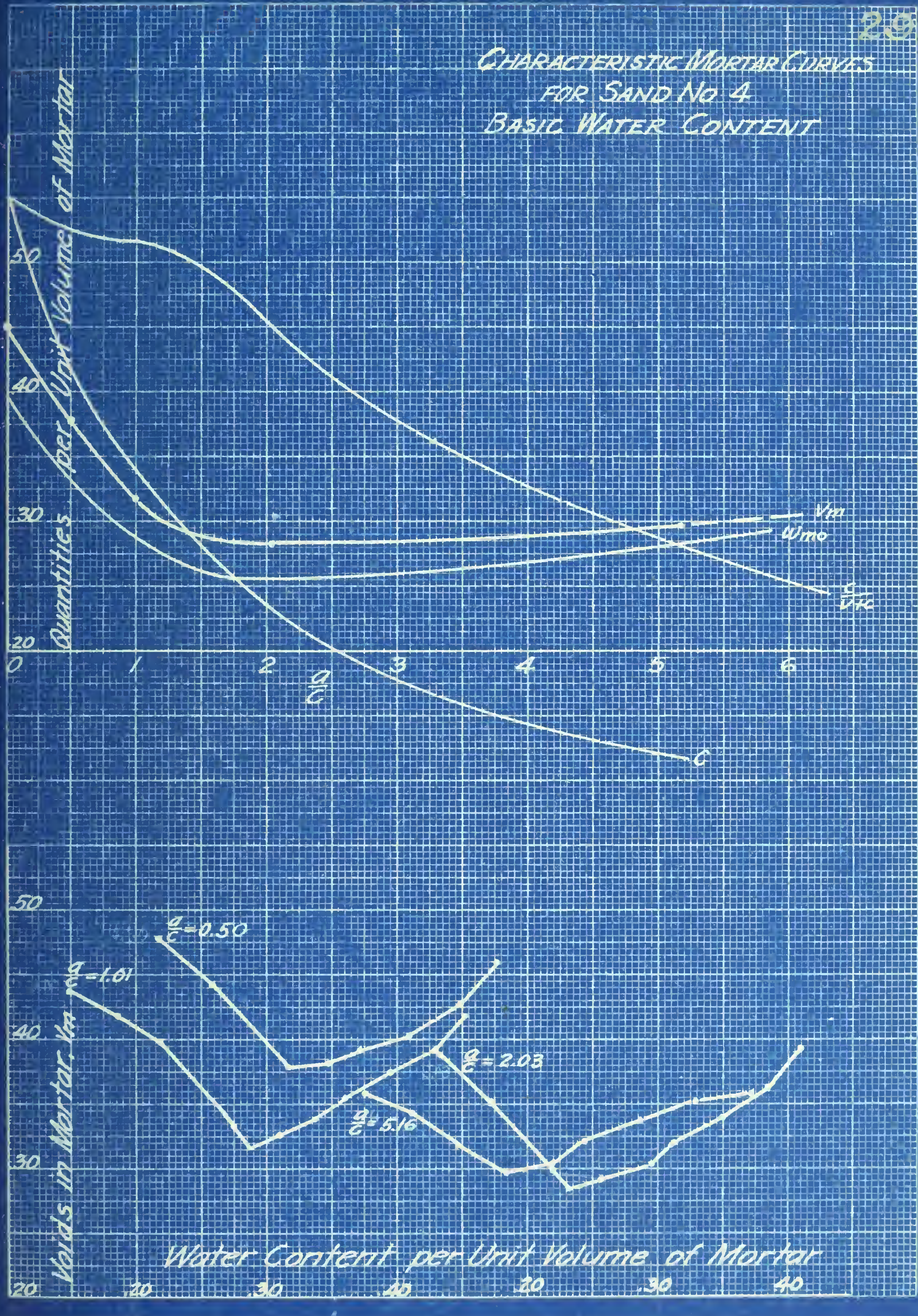
Diagram showing the Relation between Strength and the Water cement Ratio.- This relation was plotted for all the concretes made of natural sands and those made with artificially graded sands. The concretes are referred to by the sand number of which the concrete was made.

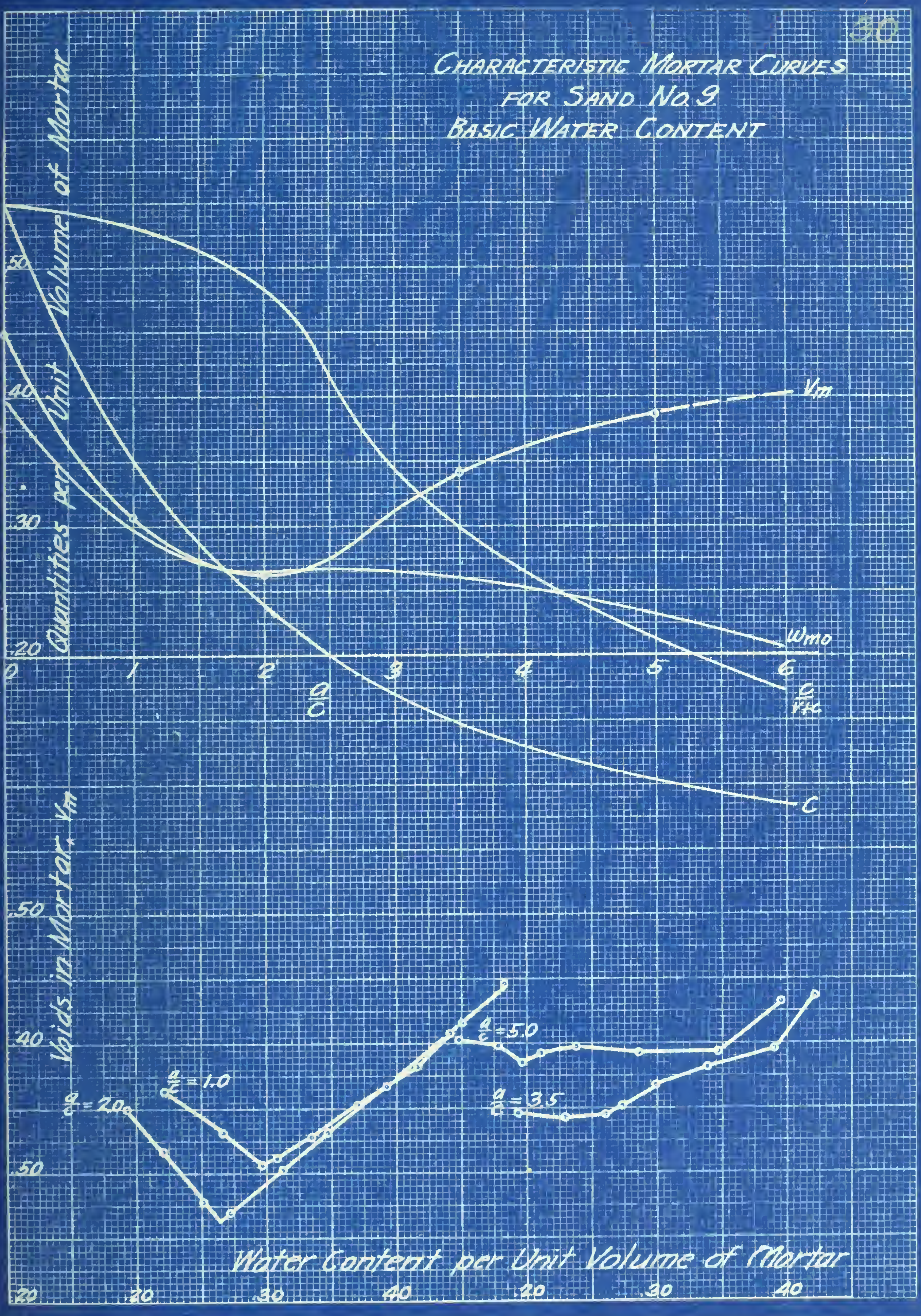
Diagrams showing the Relation Between Strength and Cement-Space Ratio.- One diagram was plotted showing the average results of all the concretes made from natural sands and the concretes made from the artificially graded sands at basic water content. The other diagrams give the average results ofthe concretes made from the three artificially graded sands No. 31, 32 and 36.

13. Explanation of Photographs.- The photographs are self explanatory except possibly in the case of the photographs of the sands. With each natural sand there is a sand called an artificial sand. This sand was made of Attica sand to the same grading as the natural sand. This artifical sand was used to compare the strength of the various sands. This set of tests were called adhesion

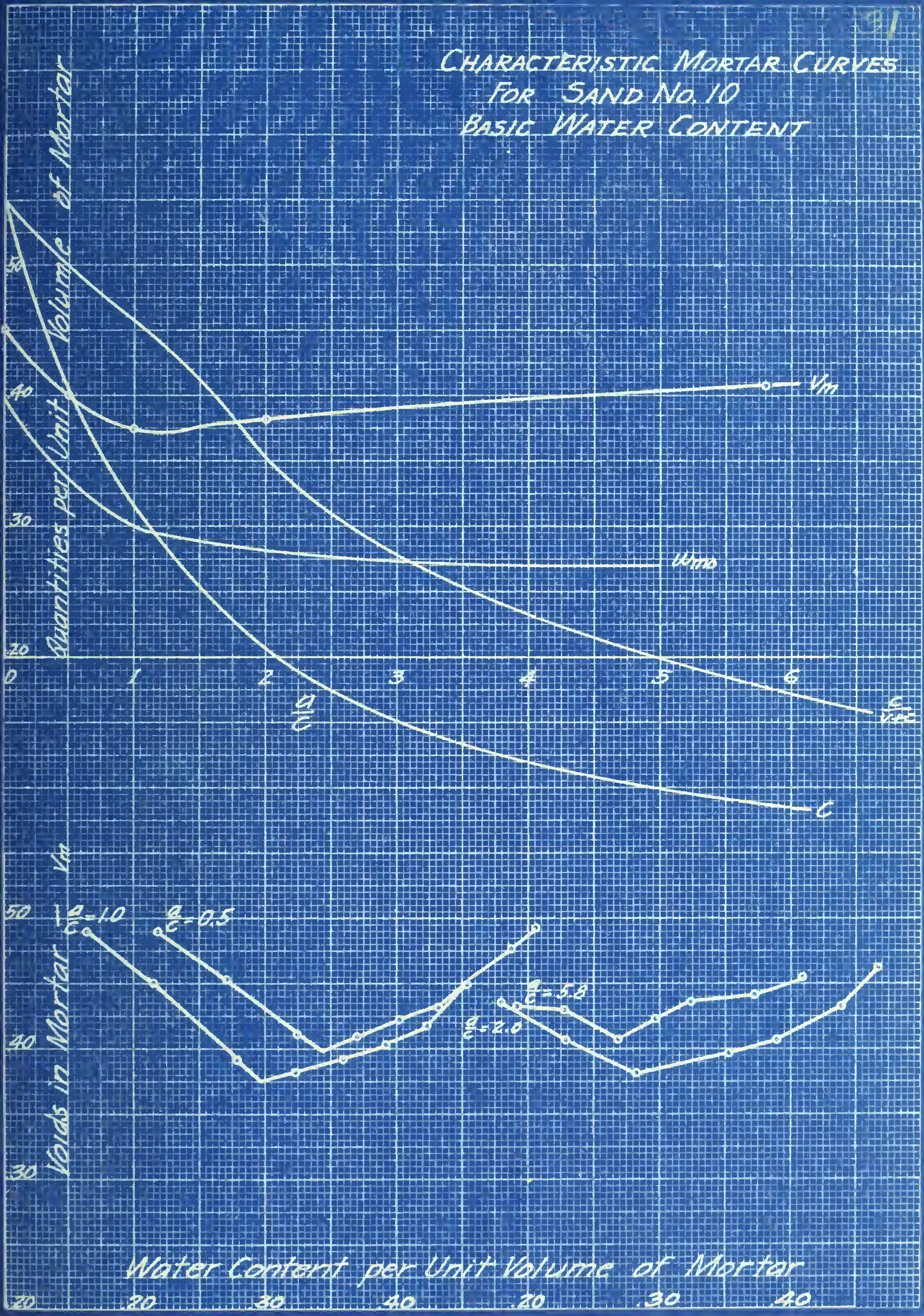
tests. These tests were made as a part of this investigation but are not reported in this thesis.

On the diagram for cement-sapce ratio and water-cement ratio the expression $\frac{W'}{W_{mo}}$ was used in the symbols. The expression is the ratio of the water used in the mix to the water in the mix at basic water content and does not refer to water per cu. ft. of concrete. The actual water content ratio varied so it could not be used as a symbol. The water content ratio can be found from the concrete data.

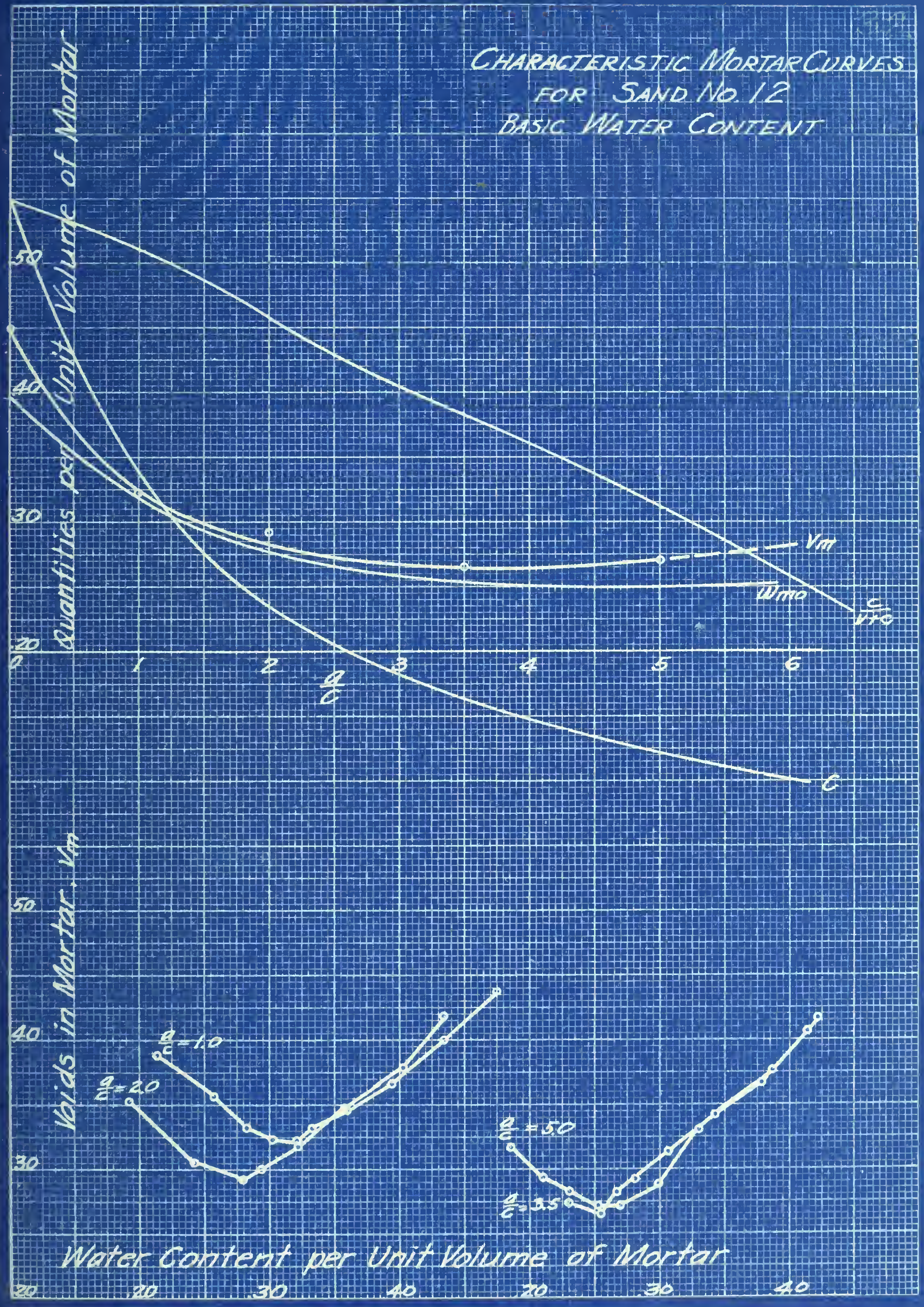

CHARACTERISTIC MORTAR CURVES
FOR SAND No 4
BASIC WATER CONTENT
Quantities per Unit Volume of Mortar
V_m
w_{mo}
$\frac{c}{v_{rc}}$
C
$\frac{a}{c}$
0
1
2
3
4
5
6
20
30
40
50
$\frac{a}{c}$=0.50
$\frac{a}{c}$=1.01
$\frac{a}{c}$=2.03
$\frac{a}{c}$=5.16
Voids in Mortar, V_m
Water Content per Unit Volume of Mortar



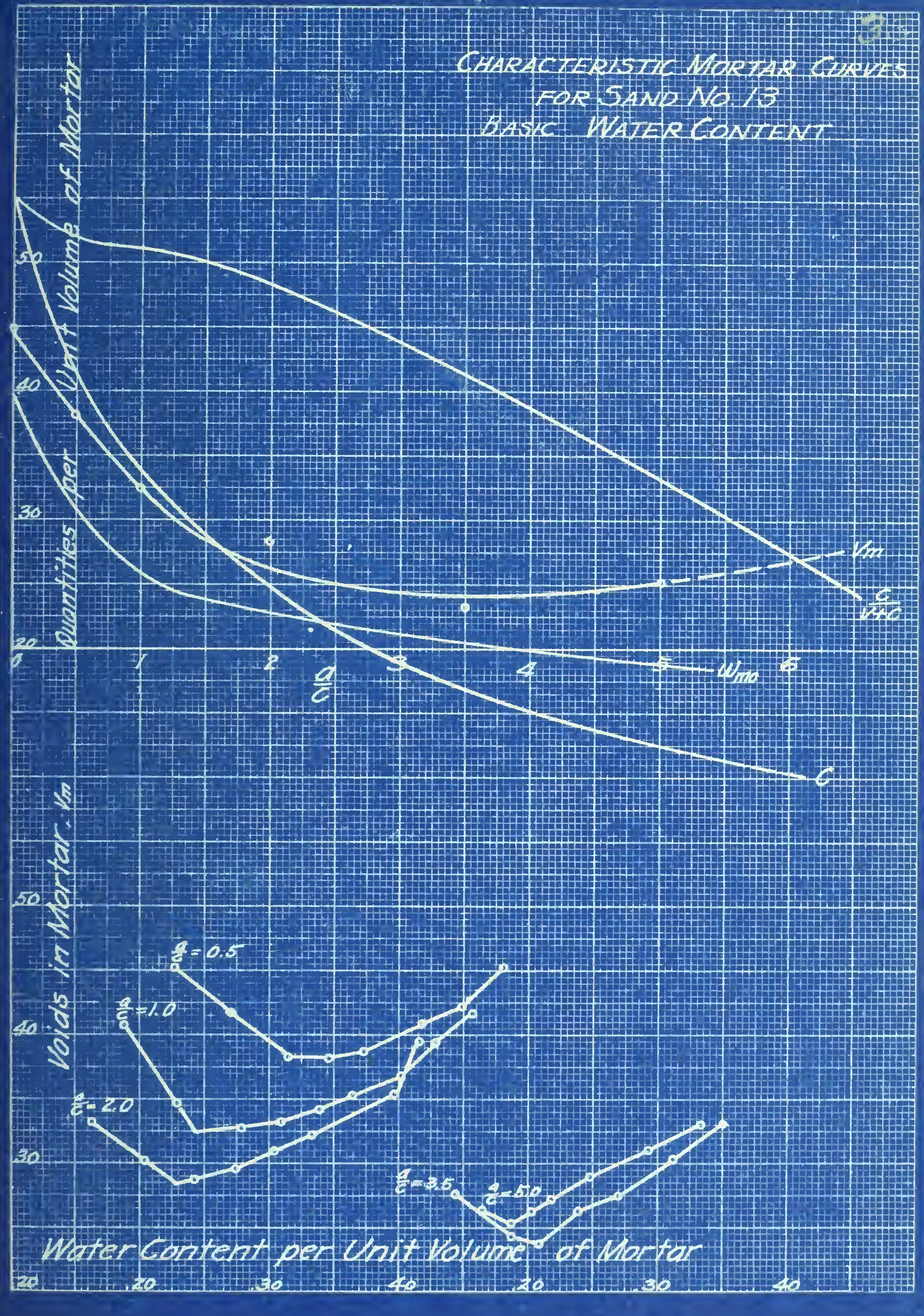
CHARACTERISTIC MORTAR CURVES
FOR SAND NO. 9
BASIC WATER CONTENT
Quantities per Unit Volume of Mortar
.50
.40
.30
.20
0
1
2
3
4
5
6
a/c
Vm
Wmo
c/v+c
C
Voids in Mortar, Vm
.50
.40
.30
a/c = 2.0
a/c = 1.0
a/c = 5.0
a/c = 3.5
Water Content per Unit Volume of Mortar
20
20
30
40
20
30
40



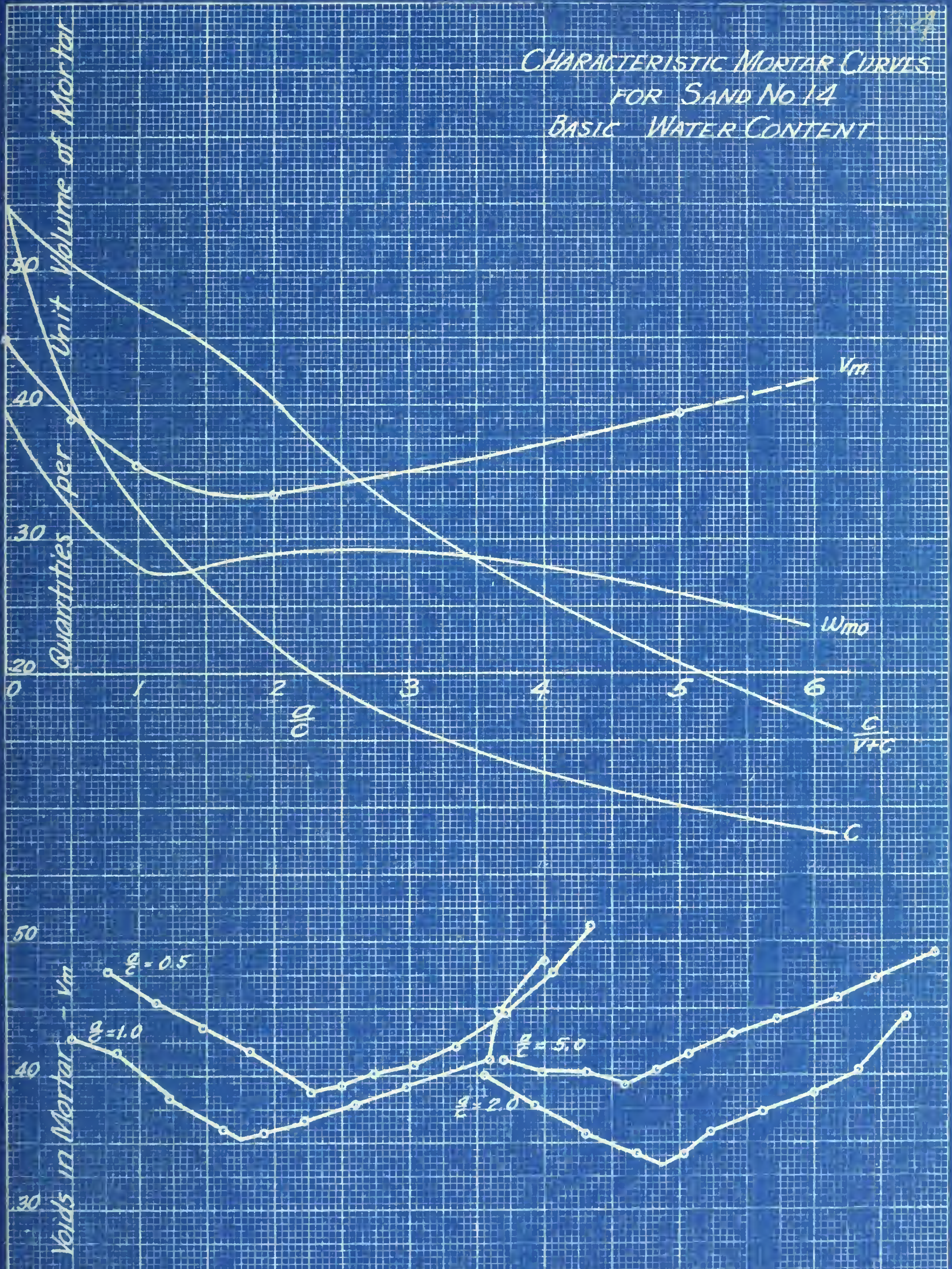
91
CHARACTERISTIC MORTAR CURVES
FOR SAND No. 10
BASIC WATER CONTENT
Quantities per Unit Volume of Mortar
Vm
Wmo
C
a/c
Voids in Mortar Vm
a/c=1.0
a/c=0.5
a/c=5.8
a/c=2.0
Water Content per Unit Volume of Mortar



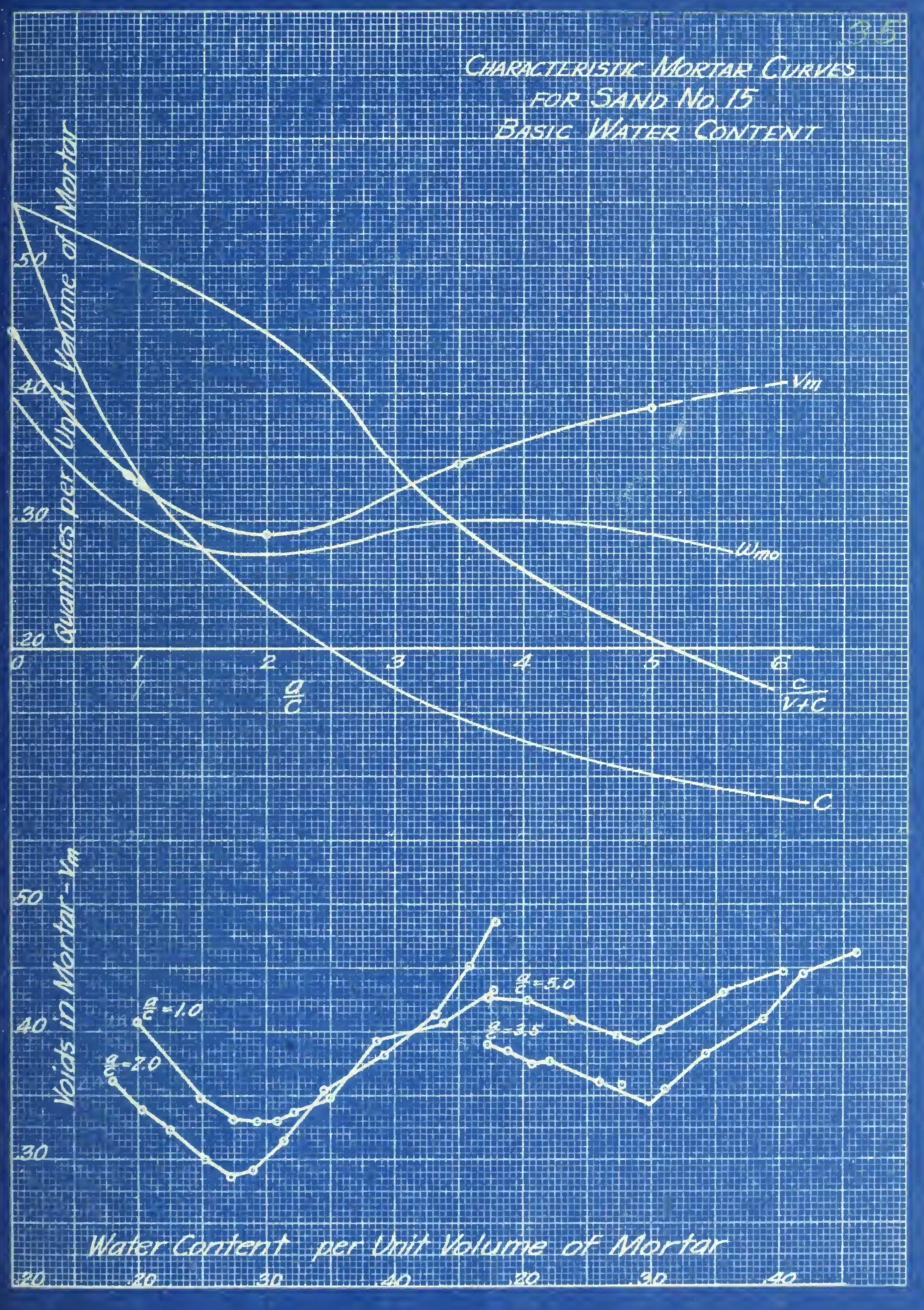
CHARACTERISTIC MORTAR CURVES
FOR SAND No. 12
BASIC WATER CONTENT
Quantities per Unit Volume of Mortar
Vm
Wmo
c/Vro
C
a/c
Voids in Mortar, Vm
a/c = 1.0
a/c = 2.0
a/c = 5.0
a/c = 3.5
Water Content per Unit Volume of Mortar



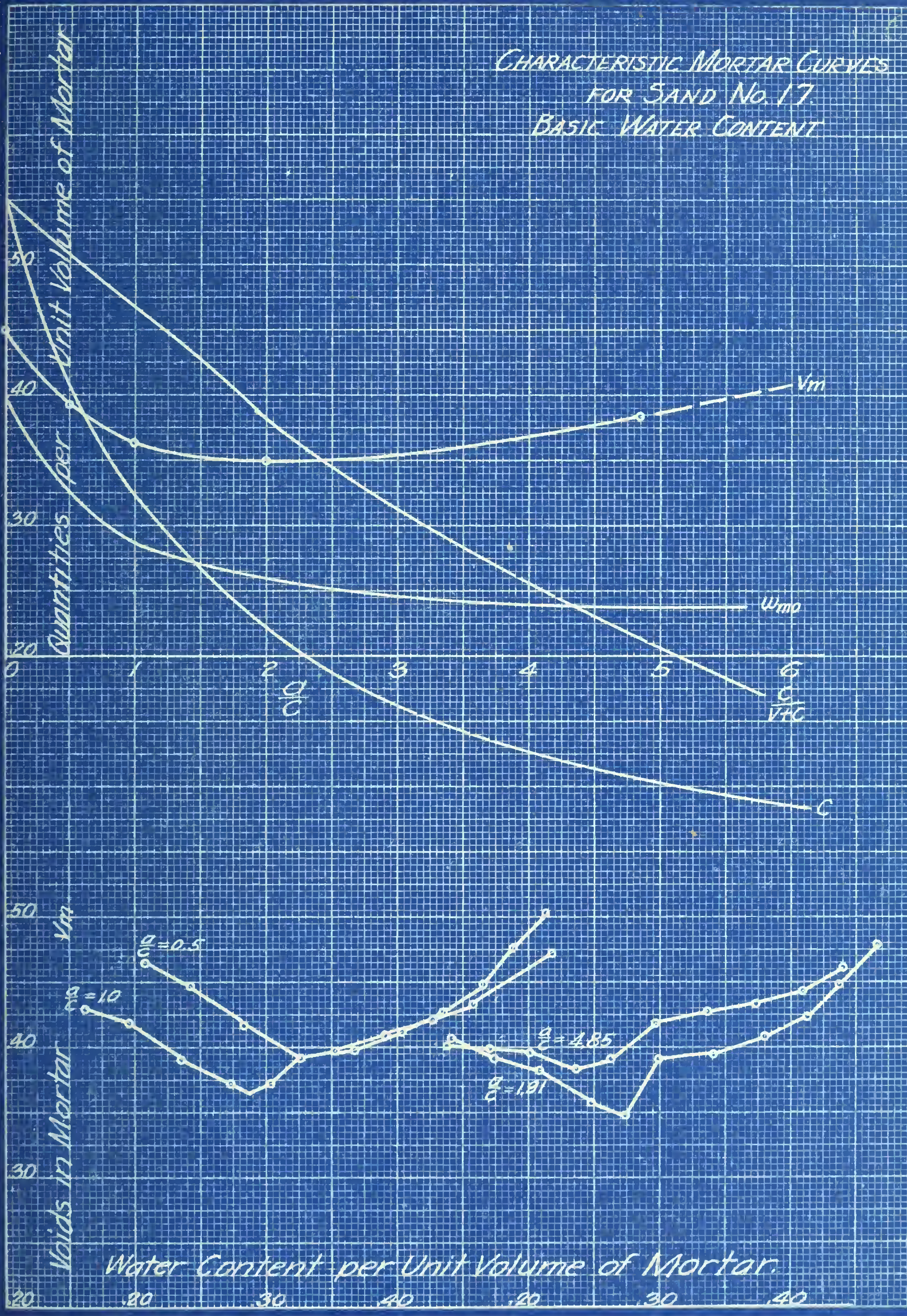
CHARACTERISTIC MORTAR CURVES
FOR SAND No 13
BASIC WATER CONTENT
Quantities per Unit Volume of Mortar
Vm
c/v+c
Wmo
a/c
C
Voids in Mortar. Vm
a/c = 0.5
a/c = 1.0
a/c = 2.0
a/c = 3.5
a/c = 5.0
Water Content per Unit Volume of Mortar



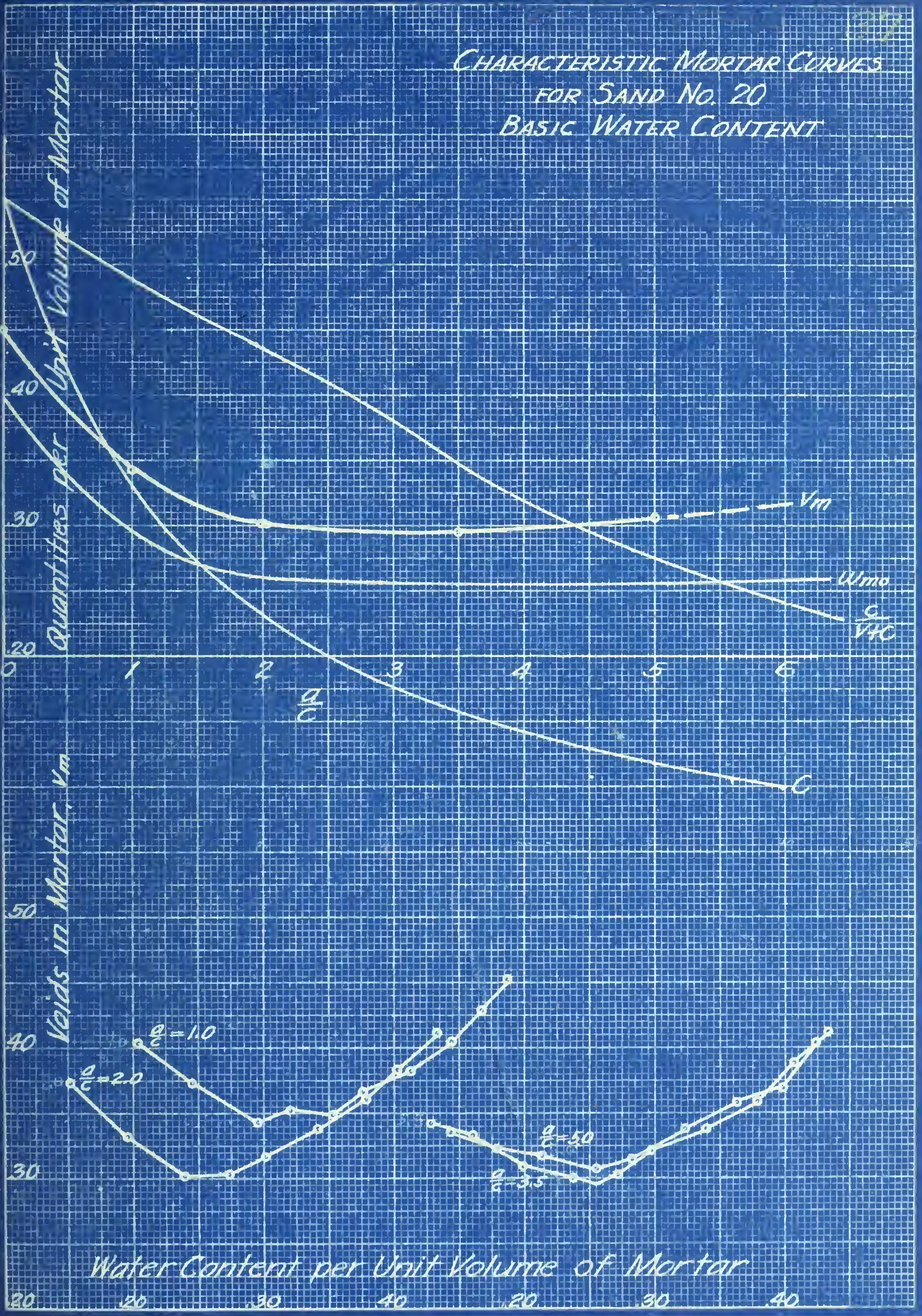
CHARACTERISTIC MORTAR CURVES
FOR SAND No 14
BASIC WATER CONTENT
Quantities per Unit Volume of Mortar
Vm
Wmo
C/(V+C)
C
a/c
a/c = 0.5
a/c = 1.0
a/c = 5.0
a/c = 2.0
Voids in Mortar - Vm
Water Content per Unit Volume of Mortar



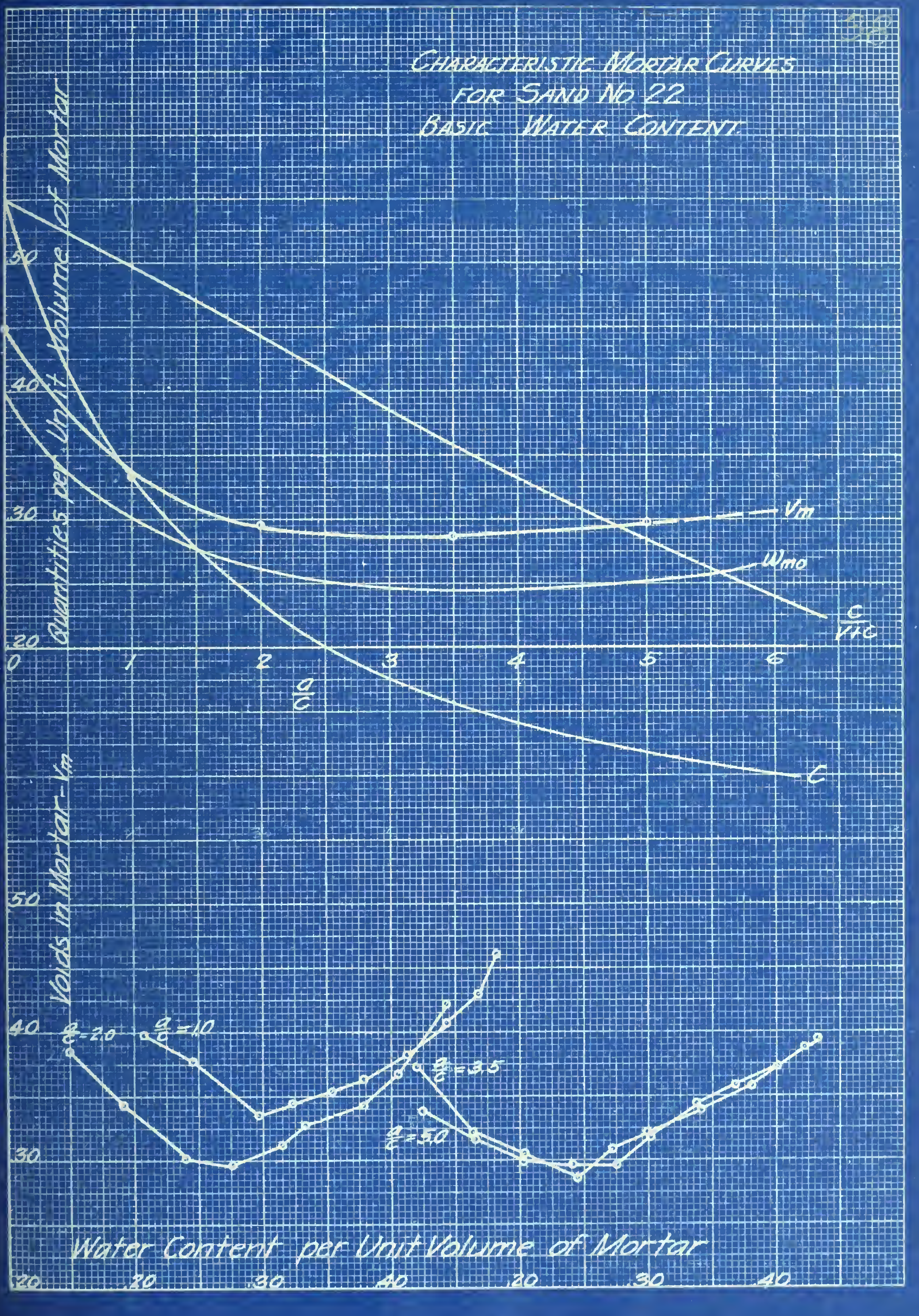
CHARACTERISTIC MORTAR CURVES
FOR SAND No. 15
BASIC WATER CONTENT
Quantities per Unit Volume of Mortar
Vm
Wmo
C
c/(V+C)
a/c
Voids in Mortar - Vm
a/c = 1.0
a/c = 2.0
a/c = 5.0
a/c = 3.5
Water Content per Unit Volume of Mortar

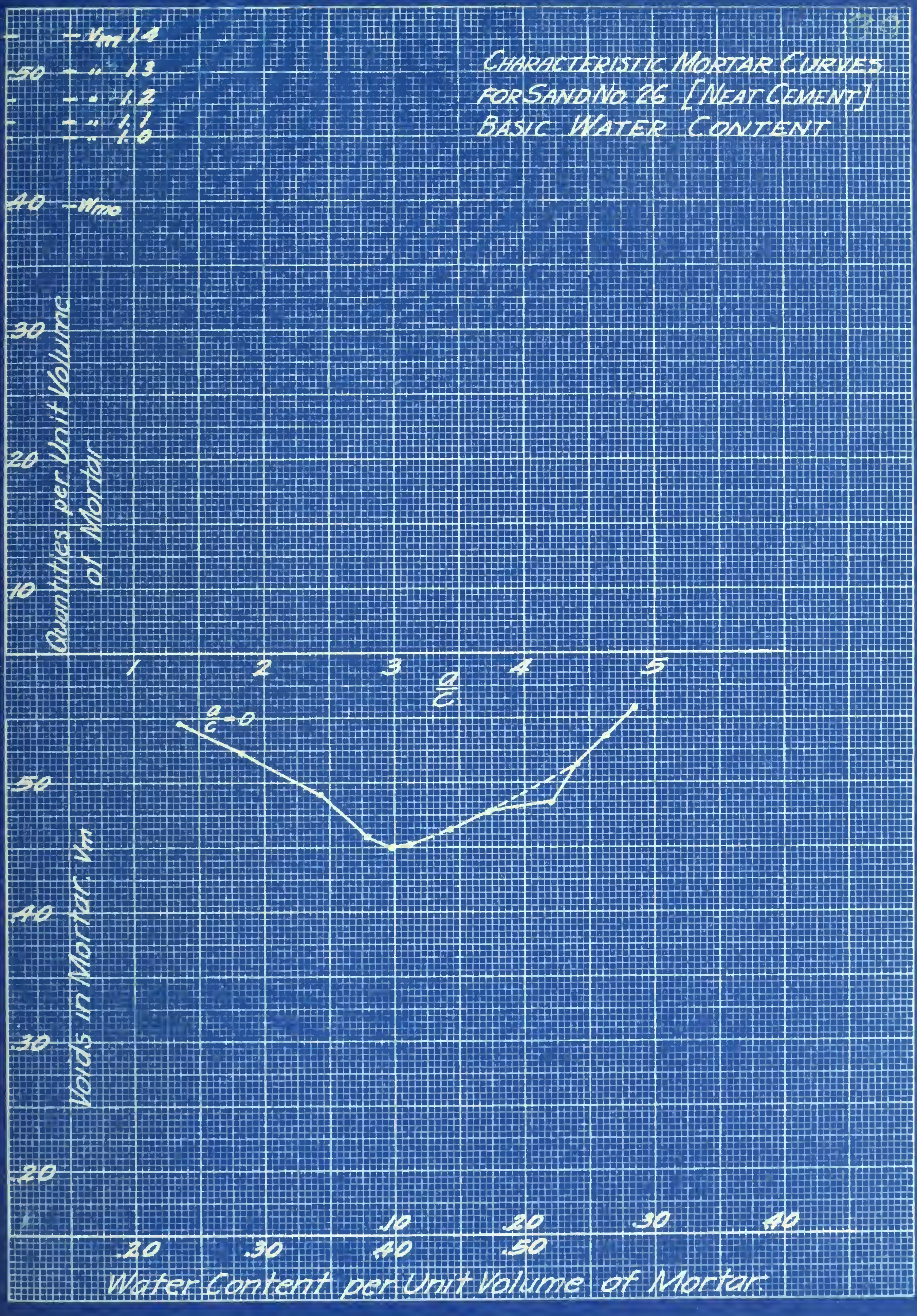


CHARACTERISTIC MORTAR CURVES
FOR SAND No. 17
BASIC WATER CONTENT
Quantities per Unit Volume of Mortar
Vm
w_{mo}
$\frac{C}{V+C}$
C
$\frac{a}{C}$
$\frac{a}{c}=0.5$
$\frac{a}{c}=1.0$
$\frac{a}{c}=4.85$
$\frac{a}{c}=1.91$
Voids in Mortar Vm
Water Content per Unit Volume of Mortar

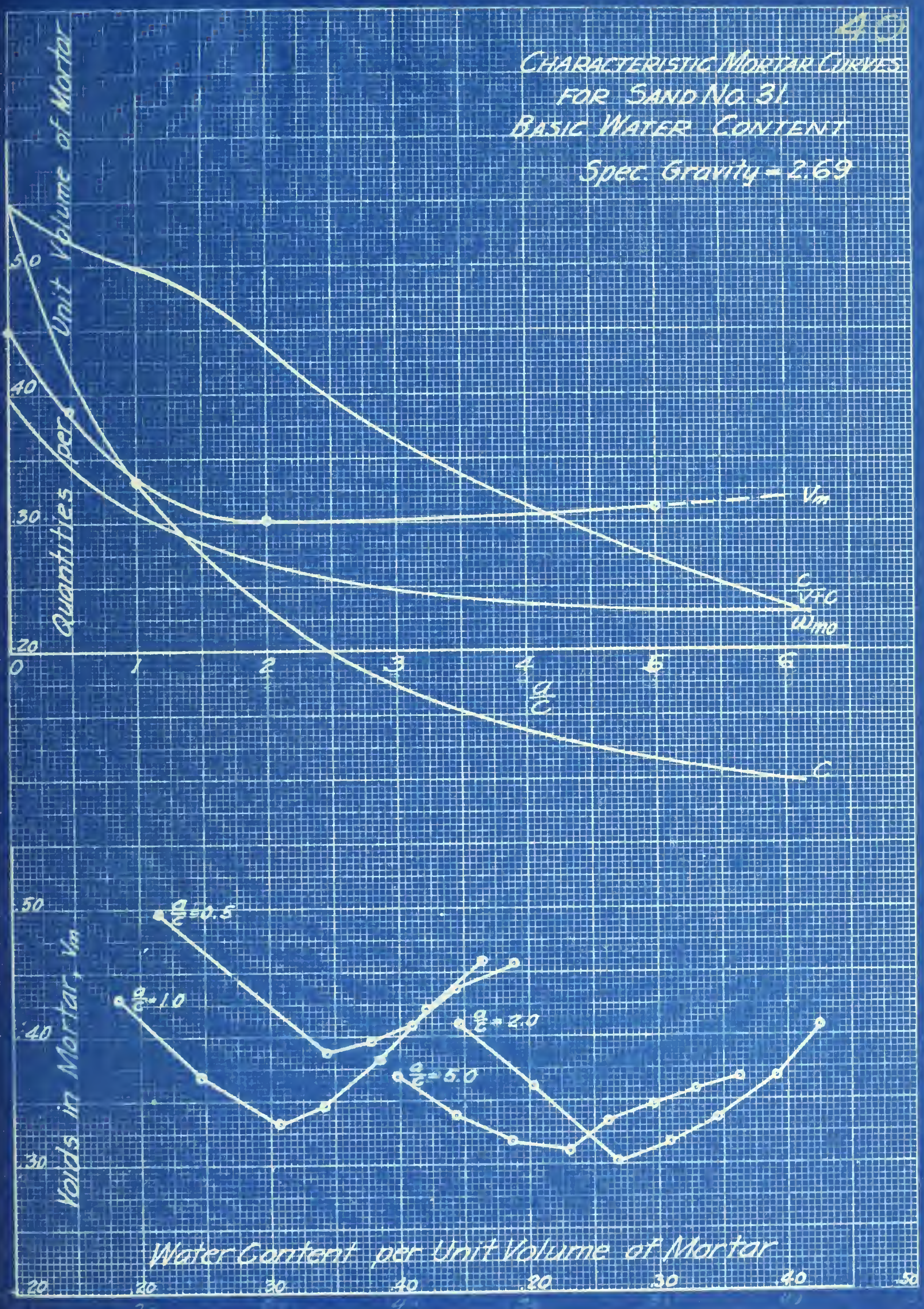


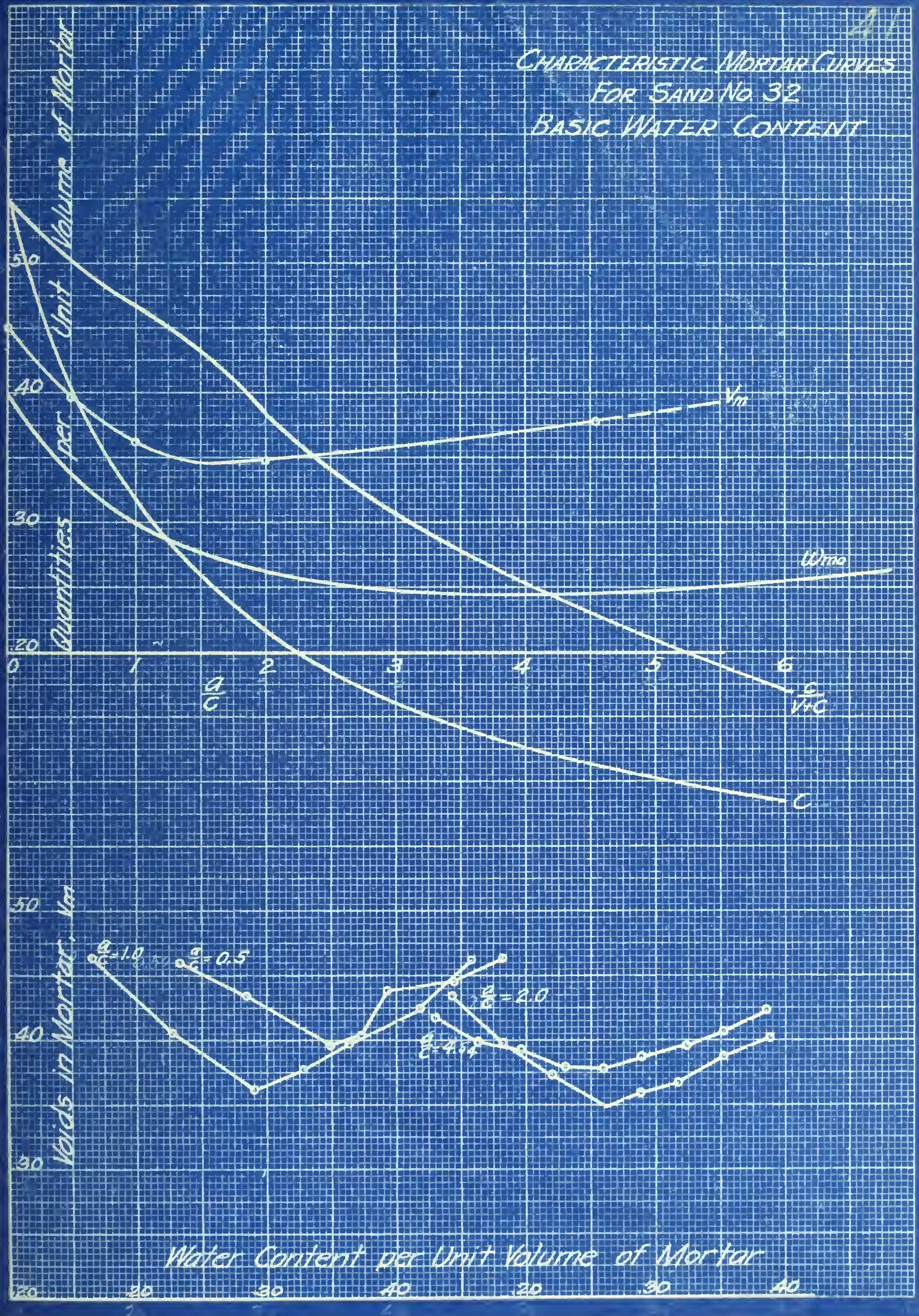
CHARACTERISTIC MORTAR CURVES
FOR SAND NO. 20
BASIC WATER CONTENT
Quantities per Unit Volume of Mortar
Vm
Wmo
c/(V+C)
C
a/c
Voids in Mortar, Vm
a/c = 1.0
a/c = 2.0
a/c = 5.0
a/c = 3.5
Water Content per Unit Volume of Mortar

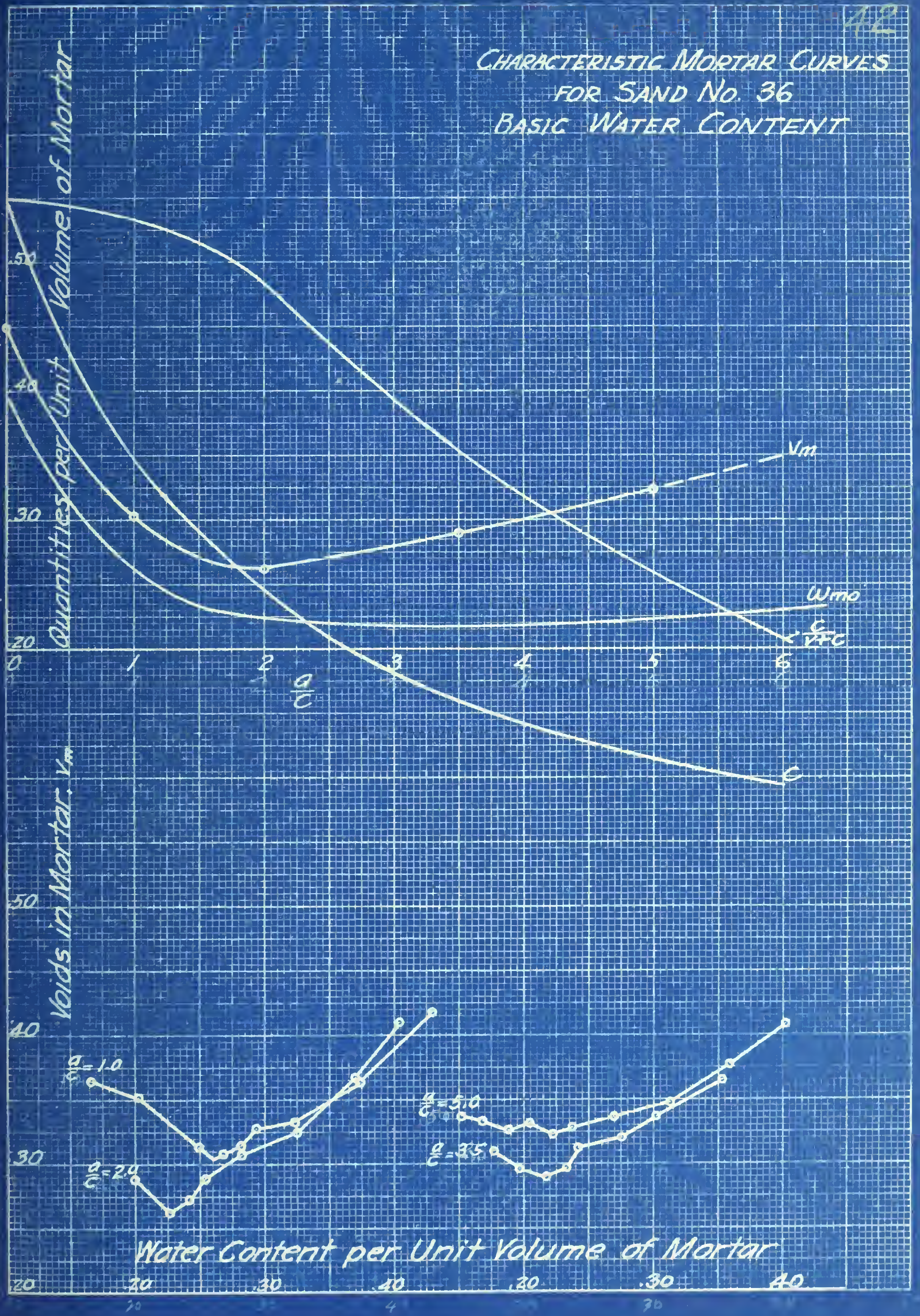

CHARACTERISTIC MORTAR CURVES
FOR SAND NO 22
BASIC WATER CONTENT
Quantities per Unit Volume of Mortar
Vm
Wmo
c/(V+c)
C
a/c
Voids in Mortar-Vm
a/c=2.0
a/c=1.0
a/c=3.5
a/c=5.0
Water Content per Unit Volume of Mortar



CHARACTERISTIC MORTAR CURVES
FOR SAND NO. 26 [NEAT CEMENT]
BASIC WATER CONTENT
Vm 1.4
1.3
1.2
1.1
1.0
Wmo
Quantities per Unit Volume of Mortar
Voids in Mortar, Vm
a/c
a/c = 0
Water Content per Unit Volume of Mortar


CHARACTERISTIC MORTAR CURVES
FOR SAND NO. 31.
BASIC WATER CONTENT
Spec. Gravity = 2.69
Quantities per Unit Volume of Mortar
.50
.40
.30
.20
0
1
2
3
4
5
6
a/c
Vm
c/(v+c)
ωmo
C
Voids in Mortar, Vm
a/c = 0.5
a/c = 1.0
a/c = 2.0
a/c = 5.0
Water Content per Unit Volume of Mortar
20
20
30
40
20
30
40
50


A1
CHARACTERISTIC MORTAR CURVES
FOR SAND No 32
BASIC WATER CONTENT
Quantities per Unit Volume of Mortar
50
40
30
20
0
1
2
3
4
5
6
a/c
V_m
W_{mo}
c/V+C
C
Voids in Mortar, V_m
50
40
30
a/c = 1.0
a/c = 0.5
a/c = 2.0
a/c = 4.54
Water Content per Unit Volume of Mortar
20
30
40
20
30
40


42
CHARACTERISTIC MORTAR CURVES
FOR SAND No. 36
BASIC WATER CONTENT
Quantities per Unit Volume of Mortar
Voids in Mortar, V_m
V_m
W_{mo}
$\frac{c}{v+c}$
C
$\frac{a}{c}$
$\frac{a}{c} = 1.0$
$\frac{a}{c} = 2.0$
$\frac{a}{c} = 5.0$
$\frac{a}{c} = 3.5$
Water Content per Unit Volume of Mortar
.50
.40
.30
.20
0
1
2
3
4
5
6
50
40
30
20
.20
.30
.40

SAND NO. 31

NOMINAL VALUES, C= .06, B = .30

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{V+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
80	.427	.305	.061	.793	.207	3.40	.228	.230	.227	.99	2.59	.158	.178	.764	730
13	.420	.299	.060	.779	.221	3.71	.212	.230	.221	.96	2.59	.155	.175	.699	710
98	.425	.303	.061	.789	.211	3.50	.222	.230	.225	.98	2.59	.157	.177	.742	700
Av.	.424	.302	.061	.787	.213	3.54	.221	.230	.224	.97	2.59	.157	.177	.735	713
81	.422	.302	.060	.784	.216	3.58	.219	.230	.268	1.17	3.10	.187	.207	.866	510
14	.408	.291	.058	.757	.243	4.15	.19[illegible]	.230	.255	1.11	3.11	.181	.200	.748	492
99	.418	.299	.060	.777	.223	3.73	.212	.230	.264	1.15	3.10	.185	.205	.830	600
Av.	.41[illegible]	.297	.060	.773	.227	3.82	.209	.230	.262	1.14	3.10	.184	.204	.815	534
82	.409	.292	.058	.759	.241	4.13	.195	.230	.300	1.31	3.63	.212	.231	.880	357
15	.400	.286	.057	.743	.257	4.50	.182	.230	.290	1.26	3.62	.207	.226	.806	373
100	.414	.296	.059	.769	.231	3.92	.203	.230	.304	1.32	3.62	.214	.234	.923	440
Av.	.407	.291	.058	.756	.244	4.18	.193	.230	.298	1.30	3.62	.211	.230	.870	390

SAND NO. 31

NOMINAL VALUES, C = .06, B = .45

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
71	.320	.451	.060	.831	.169	2.83	.261	.230	.231	1.00	2.12	.127	.148	.747	1090
278	.320	.451	.060	.831	.169	2.81	.262	.230	.231	1.00	2.11	.127	.148	.752	1217
95	.323	.455	.061	.839	.161	2.67	.273	.230	.235	1;02	2.11	.128	.149	.790	1120
Av.	.321	.452	.060	.833	.167	2.77	.265	.230	.232	1.01	2.11	.127	.148	.763	1140
72	.319	.449	.060	.828	.172	2.89	.257	.230	.276	2.20	2.55	.152	.172	.880	690
339	.315	.443	.059	.817	.183	3.10	.244	.230	.270	1.17	2.54	.150	.170	.820	725
96	317	.447	.060	.824	.176	2.88	.252	.230	.273	1.19	2.54	.151	.172	.854	850
Av.	.317	.446	.060	.823	.177	2.95	.251	.230	.273	1.19	2.54	.151	.171	.851	755
73	.309	.435	.058	.802	.198	3.41	.227	.230	.305	1.33	2.97	.172	.192	.870	470
340	.311	.438	.058	.807	.193	3.31	.232	.230	.308	1.34	2.97	.173	.193	.895	665
97	.314	.442	.058	.815	.185	3.16	.241	.230	.314	1.38	2.97	.175	.195	.941	570
Av.	.311	.438	.058	.808	.192	3.29	.233	.230	.309	1.34	2.97	.173	.193	.902	426
261	.306	.431	.057	.794	.206	3.59	.218	.230	.342	1.49	3.40	.195	.215	.946	465
276	.306	.431	.057	.794	.206	3.61	.217	.230	.343	1.49	3.40	.195	.215	.942	550
222	.301	.436	.058	.795	.205	3.39	.228	.230	.350	1.52	3.39	.197	.217	1.000	510
Av.	.304	.433	.057	.794	.206	3.53	.221	.230	.345	1.50	3.40	.196	.216	.962	475

Sand No. 31

NOMINAL VALUES, C = .06, B = .50

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
199	.281	.492	.059	.832	.168	2.87	.258	.232	.276	1.19	2.38	.140	.161	.828	880
181	.288	.488	.059	.835	.165	2.97	.252	.232	.272	1.17	2.38	.139	.160	.800	860
178	.277	.486	.058	.821	.179	3.09	.244	.232	.269	1.16	2.37	.138	.159	.767	800
Av.	.282	.489	.059	.830	.170	2.98	.251	.232	.272	1.17	2.38	.139	.160	.798	847
200	.273	.479	.057	.810	.190	3.32	.231	.232	.305	1.32	2.78	.159	.180	.838	630
179	.277	.486	.058	.821	.179	3.21	.237	.232	.313	1.35	2.77	.161	.182	.862	590
Av.	.275	.482	.058	.815	.185	3.26	.234	.232	.309	1.33	2.77	.160	.181	.850	610
183	.278	.487	.058	.823	.167	3.06	.246	.232	.359	1.55	3.16	.184	.205	1.030	560
180	.277	.486	.058	.821	.179	3.57	.219	.232	.356	1.53	3.15	.183	.204	.880	465
Av.	.277	.486	.058	.822	.173	3.31	.232	.232	.357	1.54	3.15	.183	.204	.955	512

SAND NO. 31

NOMINAL VALUES c = .10, b = .30

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
213	.390	.303	.101	.793	.207	2.05	.328	.237	.250	1.05	1.72	.173	.191	.836	1940
10	.386	.300	.100	.785	.215	2.15	.317	.237	.244	1.03	1.72	.171	.190	.800	1940
83	.392	.305	.102	.799	.201	1.98	.336	.237	.251	1.06	1.72	.174	.193	.866	1870
Av.	.389	.302	.101	.792	.208	2.06	.327	.237	.248	1.04	1.72	.173	.191	.833	1916
214	.381	.297	.099	.777	.223	2.26	.307	.237	.289	1.22	2.07	.204	.222	.915	1340
11	.379	.294	.098	.771	.229	2.34	.300	.237	.286	1.21	2.06	.202	.220	.882	1150
84	.382	.297	.099	.778	.222	2.24	.309	.237	.290	1.22	2.06	.204	.222	.919	1180
Av.	.381	.296	.099	.775	.225	2.28	.305	.237	.288	1.22	2.06	.203	.221	.905	1223
215	.376	.292	.097	.765	.235	2.42	.293	.237	.329	1.38	2.40	.233	.252	.992	1020
12	.370	.287	.096	.752	.248	2.60	.278	.237	.321	1.35	2.40	.229	.247	.924	770
85	.376	.292	.097	.765	.235	2.42	.293	.237	.332	1.40	2.42	.235	.253	1.000	790
Av.	.374	.290	.097	.761	.239	2.48	.288	.237	.327	1.38	2.41	.232	.251	.972	860
277	.364	.283	.094	.740	.260	2.75	.266	.237	.368	1.55	2.81	.264	.275	1.020	720
216	.370	.287	.096	.753	.247	2.58	.279	.237	.376	1.58	2.80	.268	.280	1.085	815
247	.360	.280	.093	.733	.267	2.87	.259	.237	.362	1.57	2.80	.261	.273	.978	975
Av.	.364	.283	.094	.742	.258	2.73	.268	.237	.369	1.56	2.80	.264	.276	1.030	837

SAND NO. 31

NOMINAL VALUES, C = .10 B = .45

Cyl No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
335	.277	.437	.097	.810	.190	1.96	.338	.250	.242	.97	1.40	.136	.155	.716	2590
74	.285	.450	.100	.835	.165	1.65	.377	.250	.255	1.02	1.40	.140	.160	.850	2250
89	.283	.446	.099	.828	.172	1.74	.366	.250	.251	1.01	1.40	.139	.158	.808	3300
Av.	.281	.444	.099	.824	.176	1.78	.361	.250	.249	1.00	1.40	.138	.158	.791	2713
20	.280	.441	.098	.819	.181	1.85	.351	.250	.296	1.18	1.69	.165	.185	.912	2060
75	.280	.441	.098	.819	.181	1.85	.351	.250	.296	1.18	1.69	.165	.185	.912	1760
90	.280	.442	.098	.819	.181	1.85	.351	.250	.296	1.18	1.69	.165	.185	.912	2040
Av.	.280	.441	.098	.819	.181	1.85	.351	.250	.296	1.18	1.69	.165	.185	.912	1953
337	.272	.430	.095	.797	.203	2.13	.320	.250	.330	1.32	1.97	.188	.207	.926	1080
21	.275	.434	.096	.805	.195	2.01	.332	.250	.336	1.34	1.97	.190	.209	.980	1230
76	.274	.433	.096	.804	.196	2.04	.329	.250	.333	1.33	1.97	.189	.208	.965	1140
Av.	.274	.432	.096	.802	.198	2.06	.327	.250	.333	1.33	1.97	.189	.208	.957	1150
274	.266	.423	.094	.783	.217	2.29	.304	.250	.368	1.47	2.26	.212	.230	.987	800
221	.272	.430	.095	.797	.203	2.13	.320	.250	.377	1.47	2.26	.215	.234	1.060	935
244	.269	.415	.092	.776	.224	2.50	.286	.250	.356	1.46	2.26	.208	.226	.905	1,315
Av.	.269	.423	.094	.786	.214	2.31	.303	.250	.367	1.47	2.26	.212	.230	.984	1,017

SAND NO. 31

NOMINAL VALUES, C = .10 B = .50

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
341	.245	.489	.098	.832	.168	1.72	.368	.256	.256	1.00	1.34	.131	.151	.780	2720
104	.247	.493	.099	.839	.161	1.63	.380	.256	.261	1.02	1.34	.132	.152	.824	3000
63	.262	.524	.105	.891	.109	1.49	.401	.256	.296	1.16	1.35	.141	.162	.904	2540
Av.	.251	.502	.100	.854	.146	1.61	.383	.256	.271	1.06	1.34	.135	.155	.803	2750
342	.242	.483	.097	.821	.179	1.86	.350	.256	.300	1.17	1.61	.155	.175	.866	1800
105	.243	.486	.097	.827	.173	1.78	.360	.256	.303	1.18	1.61	.156	.176	.902	1940
64	.243	.485	.097	.825	.175	1.81	.356	.256	.303	1.18	1.61	.156	.176	.892	1470
31	.244	.488	.098	.830	.170	1.74	.365	.256	.307	1.20	1.61	.157	.177	.925	1985
Av.	.243	.485	.097	.826	.174	1.80	.357	.256	.303	1.18	1.61	.156	.176	.896	1800
343	.237	.474	.094	.806	.194	2.06	.327	.256	.338	1.32	1.88	.178	.197	.810	1092
106	.237	.474	.095	.807	.193	2.05	.328	.256	.339	1.32	1.88	.178	.197	.918	1100
65	.239	.477	.095	.811	.189	1.98	.336	.256	.342	1.34	1.88	.179	.198	.948	1110
32	.238	.476	.095	.810	.190	2.01	.332	.256	.342	1.34	1.88	.179	.198	.938	1156
Av.	.238	.475	.095	.808	.192	2.02	.331	.256	.341	1.33	1.88	.178	.197	.903	1115
248	.225	.450	.090	.765	.235	2.63	.276	.256	.351	1.37	2.15	.193	.211	.818	1090
259	.231	.462	.092	.785	.215	2.33	.300	.256	.368	1.44	2.15	.198	.217	.922	880
280	.234	.468	.094	.796	.204	2.18	.314	.256	.378	1.47	2.15	.201	.220	.986	860
224	.235	.469	.094	.797	.203	2.17	.316	.256	.379	1.48	2.15	.201	.220	.991	995
Av.	.234	.462	.092	.786	.214	2.32	.302	.256	.369	1.44	2.15	.198	.217	.929	956

SAND NO. 31

NOMINAL VALUES C = .15, B = .30

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
7	.338	.297	.149	.784	.216	1.46	.407	.262	.259	.95	1.22	.182	.200	.844	3640
86	.342	.301	.151	.794	.206	1.37	.422	.262	.263	1.01	1.22	.184	.202	.894	3440
92	.341	.300	.150	.791	.209	1.39	.419	.262	.263	1.01	1.23	.184	.201	.885	4010
Av.	.340	.300	.150	.790	.210	1.40	.416	.262	.261	.99	1.22	.183	.201	.874	3697
8	.334	.294	.147	.775	.225	1.53	.395	.262	.307	1.17	1.48	.217	.234	.965	2550
87	.334	.294	.147	.775	.225	1.53	.395	.262	.307	1.17	1.48	.217	.234	.965	2710
93	.336	.296	.148	.780	.220	1.48	.403	.262	.310	1.18	1.47	.218	.235	.996	2770
Av.	.335	.295	.147	.777	.223	1.51	.398	.262	.308	1.17	1.47	.217	.234	.975	2677
9	.332	.284	.143	.749	.251	1.77	.362	.262	.341	1.30	1.71	.244	.261	.969	1550
88	.331	.291	.146	.768	.232	1.60	.385	.262	.354	1.35	1.73	.251	.268	1.080	1670
94	.319	.281	.141	.741	.259	1.85	.351	.262	.337	1.29	1.72	.242	.258	.935	1820
Av.	324	.285	.143	.753	.247	1.74	.366	.262	.344	1.31	1.72	.246	.262	.995	1680
246	.312	.275	.137	.724	.276	2.01	.332	2.62	.373	1.42	1.97	.270	.285	.979	1510
260	.314	.276	.138	.728	.272	1.97	.337	2.62	.374	1.43	1.97	.271	.287	.997	1430
262	.316	.278	.139	.733	.267	1.92	.343	2.62	.378	1.44	1.97	.273	.291	1.022	1650
Av.	.314	.276	.138	.728	.272	1.97	.337	2.62	.375	1.43	1.97	.271	.288	.999	1530

SAND NO. 31

NOMINAL VALUES C = .15 B = .45

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
16	.228	.447	.149	.824	.176	1.18	.459	.283	.278	.98	1.03	.154	.173	.876	3430
77	.232	.453	.151	.836	.164	1.09	.478	.283	.285	1.01	1.03	.156	.175	.952	3910
101	.226	.442	.147	.815	.185	1.27	.440	.283	.272	.96	1.03	.152	.170	.818	4370
Av.	.229	.447	.149	.825	.175	1.18	.459	.283	.278	.98	1.03	.154	.173	.882	3903
17	.222	.434	.145	.801	.199	1.37	.422	.283	.318	1.12	1.24	.180	.198	.905	3400
78	.220	.429	.143	.792	.208	1.45	.408	.283	.312	1.10	1.24	.178	.196	.856	2730
102	.224	.438	.146	.808	.192	1.32	.431	.283	.324	1.15	1.24	.182	.200	.943	3620
Av.	.222	.434	.145	.800	.200	1.38	.420	.283	.318	1.12	1.24	.180	.198	.901	3250
18	.219	.429	.143	.791	.209	1.46	.406	.283	.362	1.18	1.45	.207	.225	.990	2170
79	.215	.421	.140	.776	.224	1.59	.386	.283	.374	1.32	1.47	.216	.233	.969	1840
103	.216	.423	.141	.780	.220	1.57	.389	.283	.354	1.25	1.45	.204	.222	.922	2380
Av.	.217	.424	.141	.782	.218	1.54	.393	.283	.363	1.28	1.46	.209	.227	.960	2130
279	.205	.400	.133	.738	.262	1.97	.337	.283	.370	1.31	1.67	.222	.238	.848	1575
223	.215	.421	.140	.776	.224	1.59	.386	.283	.403	1.42	1.67	.233	.250	1.000	1485
243	.212	.415	.139	.766	.234	1.68	.373	.283	.392	1.18	1.65	.229	.247	.989	2350
Av.	.211	.412	.137	.760	.240	1.74	.365	.283	.388	1.37	1.66	.228	.245	.946	1803

SAND NO. 31

NOMINAL VALUES, c = .15, b = .50

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v + c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
184	.183	.478	.143	.804	.196	1.37	.422	.294	.268	.91	.980	.140	.158	.715	4280
217	.184	.482	.144	.810	.190	1.32	.431	.294	.272	.92	.980	.141	.159	.742	4500
196	.189	.494	.148	.831	.169	1.14	.468	.294	.282	.96	.980	.145	.163	.858	4330
Av.	.185	.485	.145	.815	.185	1.28	.440	.294	.274	.93	.980	.142	.160	.772	4370
185	.185	.485	.146	.816	.184	1.26	.443	.294	.332	1.13	1.17	.171	.189	.930	3650
218	.180	.472	.141	.793	.207	1.48	.404	.294	.314	1.07	1.18	.166	.183	.798	3380
197	.187	.490	.147	.824	.176	1.20	.455	.294	.337	1.14	1.17	.172	.191	.973	3650
Av.	.184	.482	.145	.811	.189	1.31	.434	.294	.328	1.12	1.17	.170	.188	.900	3560
186	.179	.471	.141	.791	.209	1.48	.404	.294	.365	1.24	1.37	.193	.210	.923	2300
219	.180	.472	.141	.793	.207	1.46	.407	.294	.366	1.24	1.37	.193	.211	.937	2360
198	.181	.475	.142	.797	.203	1.42	.413	.294	.370	1.26	1.37	.194	.212	.960	2120
Av.	.180	.473	.141	.794	.206	1.45	.408	.294	.367	1.25	1.37	.193	.211	.940	2260
281	.171	.449	.134	.754	.246	1.84	.353	.294	.381	1.29	1.57	.210	.227	.854	1405
220	.174	.457	.137	.768	.232	1.69	.372	.294	.394	1.34	1.56	.214	.231	.926	1660
250	.174	.457	.137	.768	.232	1.70	.371	.294	.392	1.33	1.55	.213	.231	.914	1740
Av.	.173	.454	.136	.763	.237	1.74	.365	.294	.389	1.32	1.56	.212	.230	.898	1602

SAND NO. 32

NOMINAL VALUES C = .06 B = .30

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	W_{mo}	W_m	$\frac{W_m}{W_{mo}}$	$\frac{W_c}{c}$	W_c	W_{cx}	$\frac{W_c}{v}$	Unit Load
133	.386	.315	.063	.754	.236	3.57	.219	.256	.232	.91	2.52	.159	.177	.687	690
42	.364	.297	.059	.720	.280	4.72	.175	.256	.223	.87	2.64	.157	.175	.561	376
Av.	.375	.306	.061	.742	.258	4.14	.197	.256	.227	.89	2.58	.158	.176	.624	533
134	.374	.306	.061	.741	.259	4.24	.191	.256	.280	1.09	3.18	.194	.212	.750	540
43	.362	.296	.059	.717	.283	4.79	.173	.256	.266	1.04	3.16	.187	.205	.661	372
Av.	.368	.301	.060	.729	.271	4.52	.182	.256	.273	1.07	3.17	.190	.208	.706	456
135	.368	.301	.060	.729	.271	4.51	.181	.256	.318	1.24	3.69	.222	.240	.820	460
44	.364	.297	.059	.720	.280	4.72	.175	.256	.313	1.22	3.71	.220	.238	.786	357
150	.370	.302	.060	.732	.268	4.41	.185	.256	.321	1.26	3.71	.224	.242	.989	490
Av.	.367	.300	.060	.727	.273	4.55	.180	.256	.317	1.24	3.70	.222	.240	.865	436
268	.364	.364	.059	.787	.213	4.72	.175	.256	.394	1.54	4.23	.251	.269	.897	420
273	.363	.296	.059	.718	.282	4.74	.174	.256	.357	1.49	4.24	.251	.268	.894	380
151	.371	.303	.061	.735	.265	4.37	.186	.256	.369	1.44	4.24	.257	.275	.970	385
Av.	.366	.321	.060	.747	.253	4.61	.178	.256	.373	1.49	4.24	.253	.271	.920	395

SAND NO.32

NOMINAL VALUES c = .06, b = .45

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v + c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
122	.293	.462	.061	.817	.183	2.97	.252	.246	.243	.988	2.13	.131	.152	.716	1430
136	.289	.455	.060	.804	.196	3.22	.237	.246	.286	1.16	2.58	.156	.176	.800	840
123	.287	.453	.060	.800	.200	3.32	.232	.246	.294	1.19	2.68	.161	.181	.806	920
53	.276	.435	.058	.768	.232	3.98	.201	.246	.262	1.07	2.80	.148	.168	.644	614
152	.287	.452	.060	.802	.198	3.32	.232	.246	.281	1.14	2.56	.154	.175	.770	925
Ave	.284	.449	.060	.794	.206	3.46	.226	.246	.281	1.14	2.65	.155	.175	.755	825
137	.279	.440	.058	.777	.223	4.64	.177	.246	.325	1.32	3.11	.182	.195	.670	640
124	.285	.450	.060	.795	.205	3.42	.226	.246	.338	1.37	3.11	.186	.199	.908	760
54	.280	.442	.059	.781	.219	3.69	.213	.246	.331	1.35	3.10	.182	.195	.840	484
153	.284	.448	.059	.791	.209	3.49	.223	.246	.338	1.37	3.12	.186	.199	.894	775
Av.	.282	.445	.059	.786	.214	3.81	.211	.246	.334	1.35	3.11	.184	.197	.828	665
225	.278	.439	.058	.776	.224	3.81	.216	.246	.369	1.50	3.54	.207	.220	.928	505
208	.278	.438	.058	.774	.226	3.86	.212	.246	.368	1.49	3.55	.207	.219	.920	570
154	.280	.443	.059	.782	.218	3.70	.213	.246	.375	1.52	3.55	.209	.222	.960	540
Av.	.279	.440	.058	.778	.222	3.79	.213	.246	.370	1.50	3.55	.208	.220	.936	526

SAND NO. 32

NOMINAL VALUES OF c = .06, b = .50

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_c}{c}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
193	.255	.496	.059	.810	.190	3.20	.238	.244	.280	1.15	2.37	.141	.161	.742	955
172	.253	.494	.059	.806	.194	3.26	.235	.244	.277	1.14	2.37	.140	.160	.726	990
157	.260	.507	.061	.828	.172	2.81	.262	.244	.292	1.20	2.37	.144	.165	.842	1125
Av.	.256	.499	.060	.815	.185	3.09	.245	.244	.283	1.16	2.37	.142	.162	.770	1017
194	.250	.487	.058	.795	.205	3.49	.223	.244	.316	1.30	2.78	.162	.181	.795	700
173	.251	.489	.059	.799	.201	3.41	.227	.244	.317	1.30	2.77	.162	.181	.810	585
158	.266	.495	.059	.820	.180	3.24	.236	.244	.325	1.33	2.77	.164	.184	.855	670
Av.	.256	.490	.059	.805	.195	3.39	.229	.244	.319	1.31	2.77	.163	.182	.820	652
195	.247	.481	.058	.786	.214	3.72	.212	.244	.350	1.43	3.16	.182	.202	.851	580
174	.257	.500	.060	.817	.183	3.05	.247	.244	.378	1.55	3.16	.189	.209	1.030	570
175	.251	.488	.058	.797	.203	3.45	.225	.244	.362	1.48	3.16	.185	.204	.917	750
Av.	.252	.490	.059	.801	.199	3.41	.228	.244	.363	1.49	3.16	.185	.205	.933	633
267	.244	.496	.057	.797	.203	3.85	.206	.244	400	1.64	3.55	.202	.222	.923	440
271	.247	.480	.057	.784	.216	3.73	.211	.244	.394	1.61	3.56	.205	.224	.954	415
272	.243	.473	.057	.773	.227	3.94	.202	.244	.384	1.57	3.57	.202	.221	.906	417
Av.	.245	.483	.057	.785	.215	3.84	.206	.244	.393	1.61	3.56	.203	.222	.928	424

SAND NO. 32

NOMINAL VALUES c = .10, b = .30

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
125	.351	.296	.099	.746	.254	2.31	.302	.244	.239	.980	1.70	.168	.185	.728	1580
38	.356	.300	.100	.756	.244	2.43	.292	.244	.244	1.00	1.70	.171	.188	.704	1048
107	.354	.299	.100	.753	.247	2.25	.307	.244	.242	.992	1.71	.170	.187	.759	1900
Av.	.354	.298	.100	.752	.248	2.33	.300	.244	.242	.992	1.70	.170	.187	.730	1509
126	.354	.299	.100	.753	.247	2.25	.308	.244	.291	1.19	2.05	.204	.221	.911	1440
41	.347	.293	.098	.737	.261	2.69	.271	.244	.283	1.16	2.05	.200	.216	.764	1015
110	.348	.294	.098	.739	.260	2.43	.291	.244	.283	1.16	2.04	.200	.217	.841	1480
Av.	.349	.295	.099	.743	.257	2.45	.290	.244	.286	1.17	2.05	.201	.218	.839	1312
127	.347	.293	.098	.737	.261	2.45	.290	.244	.331	1.36	2.40	.234	.250	.980	1170
40	.341	.288	.096	.725	.275	2.86	.259	.244	.319	1.31	2.39	.229	.246	.836	944
109	.343	.289	.097	.729	.271	2.58	.279	.244	.323	1.32	2.38	.230	.247	.924	1180
Av.	.344	.290	.097	.730	.269	2.63	.276	.244	324	1.33	2.39	.231	.248	.913	1101
128	.342	.288	.096	.726	.274	2.62	.276	.244	.370	1.51	2.74	.263	.280	1.044	850
39	.343	.289	.096	.728	.272	2.81	.262	.244	.371	1.52	2.74	.264	.280	.975	850
108	.338	.285	.095	.718	.282	2.75	.267	.244	.364	1.49	2.74	.260	.276	.996	900
Av.	.341	.287	.096	.724	.276	2.73	.268	.244	.368	1.51	2.74	.262	.279	1.015	866

SAND NO. 32

NOMINAL VALUES c = .10, b = .45

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
138	.261	.452	.100	.813	.187	1.87	.348	.252	.256	1.01	1.40	.140	.161	.750	2550
111	.259	.448	.099	.806	.194	1.94	.340	.252	.252	1.00	1.40	.139	.159	.771	2780
Av.	.260	.450	.099	.810	.190	1.91	.344	.252	.254	1.01	1.40	.140	.160	.761	2665
50	.251	.433	.099	.783	.217	2.22	.310	.252	.284	1.13	1.63	.161	.180	.732	1542
139	.256	.444	.098	.798	.202	2.05	.328	.252	.297	1.18	1.68	.165	.184	.817	2050
112	.257	.447	.099	.803	.197	1.98	.336	.252	.300	1.19	1.67	.166	.185	.848	2480
Av.	.255	.441	.099	.795	.205	2.08	.325	.252	.294	1.17	1.66	.164	.183	.799	2024
51	.246	.445	.094	.785	.215	2.48	.287	.252	.332	1.32	1.95	.184	.203	.787	1300
140	.251	.435	.096	.782	.218	2.26	.307	.252	.333	1.32	1.95	.188	.207	.863	1500
113	.250	.433	.096	.779	.221	2.29	.304	.252	.332	1.32	1.95	.188	.206	.855	1880
Av.	.249	.438	.096	.783	.217	2.34	.299	.252	.332	1.32	1.95	.187	.205	.835	1560
210	.245	.424	.094	.763	.237	2.52	.284	.252	.360	1.43	2.20	.207	.228	.874	970
228	.251	.435	.096	.782	.218	2.25	.308	.252	.370	1.47	2.21	.213	.234	.982	1215
241	.253	.438	.097	.788	.212	2.17	.315	.252	.381	1.51	2.20	.214	.236	1.015	970
Av.	.250	.432	.096	.778	.222	2.31	.302	.252	.370	1.47	2.20	.211	.233	.957	1052

SAND NO. 32

NOMINAL VALUES c = .10, b = .50

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
159	.225	.493	.099	.817	.183	1.85	.351	.257	.251	0.98	1.29	.127	.148	.694	2850
190	.222	.488	.098	.808	.192	1.95	.339	.257	.244	0.95	1.28	.125	.146	.658	2700
164	.226	.495	.099	.820	.180	2.00	.333	.257	.252	0.98	1.28	.127	.148	.642	2800
Av.	.224	.492	.099	.815	.185	1.93	.341	.257	.249	.097	1.28	.126	.147	.665	2783
160	.225	.493	.099	.817	.183	1.85	.351	.257	.300	.117	1.54	.152	.171	.831	2350
191	.224	.491	.098	.813	.187	1.91	.343	.257	.299	1.17	1.55	.152	.170	.813	2090
165	.220	.483	.097	.800	.200	2.05	.328	.257	.288	1.12	1.54	.149	.158	.753	2145
Av.	.223	.489	.098	.810	.190	1.94	.341	.257	.296	1.15	1.54	.151	.167	.799	2195
161	.218	.482	.096	.796	.204	2.11	.322	.257	.336	1.31	1.81	.174	.192	.857	1690
192	.223	.488	.098	.809	.191	1.96	.338	.257	.344	1.34	1.80	.176	.195	.922	1770
166	.222	.487	.097	.806	.194	1.98	.336	.257	.343	1.33	1.81	.176	.195	.962	1725
Av.	.221	.486	.097	.804	.196	2.02	.332	.257	.341	1.33	1.81	.175	.194	.914	1728
269	.219	.481	.096	.796	.194	2.13	.320	.257	.382	1.49	2.06	.198	.216	.972	1240
209	.219	.481	.096	.796	.194	2.12	.320	.257	.382	1.49	2.06	.198	.216	.972	1100
229	.219	.479	.096	.794	.196	2.16	.316	.257	.378	1.47	2.06	.197	.216	.951	1345
Av.	.219	.480	.096	.795	.195	2.14	.319	.257	.381	1.48	2.06	.198	.216	.965	1228
239	.213	.468	.094	.775	.225	2.39	.295	.257	.406	1.58	2.31	.216	.234	.964	745
256	.211	.464	.093	.768	.232	2.51	.285	.257	.400	1.56	2.31	.214	.232	.923	955
266	.211	.463	.093	.767	.233	2.52	.284	.257	.398	1.55	2.31	.214	.232	.919	970
Av.	.212	.[illegible]65	.093	.770	.230	2.47	.288	.257	.401	1.56	2.31	.215	.233	.942	890

SAND NO. 32

NOMINAL VALUES OF c = .10, b = .55

Cyl. No.	a	b	c	d	v	$\underline{v}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
296	.189	.533	.097	.819	.181	1.87	.349	.264	.293	1.11	1.41	.137	.157	.757	2590
144	.189	.534	.097	.820	.180	1.86	.350	.264	.294	1.11	1.41	.137	.157	.762	2910
119	.192	.543	.099	.834	.166	1.68	.373	.264	.306	1.16	1.41	.140	.160	.844	3180
Av.	.190	.537	.098	.825	.175	1.80	.357	.264	.298	1.13	1.41	.138	.158	.788	2893
297	.188	.532	.097	.817	.183	1.88	.349	.264	.340	1.29	1.64	.159	.179	.874	1950
145	.191	.540	.097	.829	.171	1.74	365	.264	.350	1.33	1.64	.161	.181	.942	1880
120	.190	.536	.098	.824	.176	1.81	.356	.264	.345	1.31	1.64	.160	.180	.910	2300
Av.	.190	.536	.097	.823	.177	1.81	.356	.264	.345	1.31	1.64	.160	.180	.909	2040
298	.187	.538	..096	.811	.189	1.92	.342	.264	.384	1.45	1.89	.181	.200	.958	1050
146	.190	.538	.098	.806	.174	1.77	.361	.264	.398	1.51	1.89	.184	.204	1.030	1300
121	.186	.525	.095	.826	.194	2.02	.331	.264	.379	1.44	1.89	.180	.199	.934	1450
59	.187	.528	.096	.811	.189	1.96	.338	.264	.384	1.45	1.88	.181	.200	.964	1035
Av.	.188	.530	.096	.814	.186	1.92	.343	.264	.386	1.46	1.89	.182	.201	.979	1209
255	.182	.514	.093	.789	.211	2.26	.307	.264	.406	1.54	2.11	.197	.216	.934	810
263	.180	.510	.093	.783	.217	2.33	.300	.264	.400	1.52	2.11	.196	.215	.908	930
Av.	.181	.512	.093	.783	.214	2.30	.303	.264	.403	1.53	2.11	.197	.216	.921	870

SAND NO. 32

NOMINAL VALUES c = .15, b = .30

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v + c}$	W_{mo}	W_m	$\frac{W_m}{W_{mo}}$	$\frac{W_c}{c}$	W_c	W_{cx}	$\frac{W_c}{v}$	Unit Load
35	.300	.292	.146	.738	.262	1.80	.357	.262	.250	.955	1.21	.177	.193	.673	1849
60	.310	.302	.151	.763	.237	1.57	.389	.262	.262	1.00	1.21	.183	.199	.766	2930
129	.311	.303	.151	.765	.235	1.61	.383	.262	.264	1.01	1.22	.184	.200	.758	3110
Av.	.307	.299	.149	.755	.245	1.66	.378	.262	.259	.990	1.21	.181	.197	.732	2630
36	.306	.298	.249	.753	.247	1.65	.377	.262	.309	1.18	1.46	.217	.233	.883	2650
61	.302	.295	.147	.744	.256	1.73	.366	.262	.305	1.16	1.46	.215	.231	.844	2340
130	.304	.295	.148	.747	.253	1.71	.369	.262	.306	1.17	1.46	.216	.231	.854	2810
Av.	.304	.296	.148	.748	.252	1.70	.371	.262	.307	1.17	1.46	.216	.232	.860	2600
37	.297	.289	.145	.731	.269	1.85	.351	.262	.346	1.32	1.70	.246	.261	.918	1965
62	298	.291	.145	.734	.266	1.82	.355	.262	.348	1.33	1.70	.247	.262	.932	2020
131	.292	.298	.142	.732	.268	1.97	.337	.262	.345	1.32	1.70	.242	.257	.868	2080
Av.	.296	.298	.144	.733	.267	1.88	.348	.262	.346	1.32	1.70	.245	.260	.906	2022
226	.291	.283	.142	.716	.284	1.99	.334	.262	.385	1.47	1.94	.276	.291	.976	1895
212	.292	.284	.142	.718	.282	1.97	.337	.262	.387	1.48	1.95	.277	.292	.990	1545
132	.292	.284	.142	.718	.282	1.98	.336	.262	.387	1.47	1.95	.277	.292	.986	1600
Av.	.292	.284	.142	.718	.282	1.98	.336	.262	.386	1.47	1.95	.277	.292	.984	1680

SAND NO. 32
NOMINAL VALUES c = .15, b = .45

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
155	.206	.454	.151	.811	.189	1.25	.444	.282	.280	0.99	1.01	.153	.172	.810	4210
163	.205	.451	.150	.806	.194	1.28	.438	.282	.279	0.99	1.02	.153	.171	.798	4400
236	.209	.461	.153	.823	.177	1.16	.463	.282	.289	1.02	1.02	.156	.174	.882	4730
Av.	.207	.455	.151	.813	.187	1.23	.448	.282	.283	1.00	1.02	.154	.172	.830	4450
141	.202	.446	.148	.796	.204	1.37	.442	.282	.327	1.16	1.22	.181	.199	.892	3650
114	.202	.445	.148	.795	.205	1.39	.418	.282	.324	1.15	1.22	.180	.198	.875	3860
46	.202	.445	.148	.795	.205	1.38	.420	.282	.324	1.15	1.22	.180	.198	.879	3222
Av.	.202	.445	.148	.795	.205	1.38	.420	.282	.325	1.15	1.22	.180	.198	.882	3577
142	.198	.436	.145	.779	.221	1.52	.397	.282	.365	1.29	1.42	.206	.224	.937	2820
115	.199	.438	.146	.784	.216	1.49	.401	.282	.369	1.31	1.42	.207	.225	.955	2780
47	.198	.437	.146	.782	.218	1.49	.401	.282	.368	1.30	1.42	.207	.224	.950	2062
Av.	.198	.437	.146	.781	.219	1.50	.400	.282	.267	1.30	1.42	.207	.224	.947	2554
143	.195	.430	.143	.768	.232	1.61	.383	.282	.409	1.45	1.63	.233	.251	1.010	1870
116	.192	.423	.141	.756	.244	1.74	.365	.282	.397	1.41	1.62	.229	.246	.935	1680
48	.193	.425	.141	.759	.241	1.71	.369	.282	.400	1.42	1.63	.230	.247	.955	1158
Av.	.193	.426	.142	.761	.239	1.69	.372	.282	.402	1.43	1.63	.231	.248	.967	1569

SAND NO. 32

NOMINAL VALUES OF c = .15; b = .50

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	$\underline{w_{cx}}$	$\frac{w_c}{v}$	Unit Load
162	.168	.495	.148	.811	.189	1.28	.439	.292	.279	0.96	0.95	.141	.159	.747	4170
187	.169	.499	.149	.817	.183	1.23	.448	.292	.284	0.97	0.95	.142	.160	.776	4490
169	.168	.495	.148	.811	.189	1.27	.440	.292	.279	0.96	0.95	.141	.158	.750	4120
Av.	.168	.496	.149	.813	.187	1.26	.442	.292	.281	0.96	0.95	.141	.159	.758	4260
167	.167	.494	.148	.809	.191	1.29	.437	.292	.332	1.14	1.14	.168	.186	.880	4030
188	.167	.494	148	.809	.191	1.29	.437	.292	.332	1.14	1.14	.168	.186	.880	3945
170	.167	.492	.147	.806	.194	1.32	.431	.292	.329	1.13	1.14	.167	.185	.862	4090
Av.	.167	.493	.148	.808	.192	1.30	.435	.292	.331	1.14	1.14	.168	.186	.874	4022
168	.164	.485	.145	.794	.206	1.41	.415	.292	.375	1.28	1.33	.193	.211	.942	2990
189	.164	.483	.145	.792	.208	1.44	.410	.292	.372	1.27	1.32	.192	.210	.924	3060
171	.165	.487	.146	.798	.202	1.38	.420	.292	.378	1.29	1.33	.194	.211	.970	2700
Av.	.164	.485	.145	.795	.206	1.41	.415	.292	.375	1.28	1.33	.193	.211	.945	2917
270	.160	.471	.141	.772	.228	1.62	.381	.292	.404	1.38	1.52	.214	.231	.939	2200
211	.162	.479	.143	.784	.216	1.50	.400	.292	.419	1.43	1.52	.218	235	1.014	1960
227	.167	.472	.141	.780	.220	1.60	.384	.292	.405	1.39	1.52	.214	.232	.948	2050
Av.	.163	.474	.142	.779	.221	1.57	.388	.292	.409	1.40	1.52	.215	.233	.967	2070
240	.156	.460	.138	.754	.246	1.78	.360	.292	.437	1.50	1.71	.236	.252	.959	1370
257	.156	.459	.138	.753	.247	1.79	.358	.292	.435	1.49	1.70	.235	.252	.952	1350
265	.157	.464	.139	.760	.240	1.72	.368	.292	.444	1.52	1.71	.238	.255	.996	1200
Av.	156	.461	.138	.756	.245	1.76	.362	.292	.439	1.50	1.71	.236	.253	.969	1307

SAND NO. 32

NOMINAL VALUES c = .15, b = .55

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v + c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
147	.126	.530	.143	.799	.201	1.42	.413	.306	.381	1.25	1.25	.179	.197	.882	2850
117	.127	.533	.144	.804	.196	1.39	.419	.306	.386	1.26	1.25	.180	.198	.900	2930
52	.128	.545	.147	.820	.180	1.25	.444	.306	.404	1.32	1.25	.184	.202	1.005	3240
Av.	.127	.536	.145	.808	.192	1.35	.425	.306	.390	1.27	1.25	.181	.199	.929	3007
148	.126	.530	.143	.799	.201	1.43	.412	.306	.434	1.42	1.43	.204	.222	.996	1590
118	.126	.532	.144	.802	.198	1.41	.415	.306	.438	1.43	1.42	.205	.223	1.010	1500
56	.126	.528	.143	.797	.203	1.45	.408	.306	.430	1.41	1.42	.203	.221	.980	1700
Av.	.126	.530	.143	.799	.201	1.43	.412	.306	.434	1.42	1.42	.204	.222	.996	1620
242	.122	.514	.139	.775	.225	1.66	.376	.306	.457	1.49	1.60	.222	.240	.996	1330
258	.122	.513	.138	.773	.227	1.67	.375	.306	.456	1.49	1.61	.222	.239	.961	1515
264	.122	.515	.139	.776	.224	1.70	.370	.306	.460	1.51	1.60	.223	.241	.942	1530
Av.	.122	.514	.139	.775	.225	1.68	.374	.306	.458	1.50	1.60	.222	.240	.966	1458

SAND NO. 36

BASIC WATER CONTENT, VARYING C AND B

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
284	.402	.304	.061	.767	.233	3.88	.205	.235	.208	0.89	2.39	.145	.164	.618	600
319	.404	.306	.061	.771	.229	3.57	.219	.235	.210	0.89	2.39	.146	.165	.670	585
348	.403	.305	.061	.769	.231	3.82	.207	.235	.209	0.89	2.38	.145	.164	.625	600
Av.	.403	.305	.061	.769	.231	3.76	.210	.235	.209	0.89	2.39	.145	.164	.638	595
326	.310	.446	.059	.815	.185	3.08	.245	.224	.202	0.90	1.89	.112	.132	.612	1030
333	.298	.429	.057	.784	.216	3.75	.210	.224	.187	0.84	1.88	.107	.127	.500	850
350	.306	.440	.059	.805	.195	3.31	.232	.224	.196	0.87	1.83	.110	.131	.567	1040
Av.	.303	.438	.058	.801	.199	3.38	.229	.224	.195	0.87	1.87	.107	.130	.560	973
289	.353	.294	.147	.794	.206	1.40	.417	.220	.217	0.99	1.04	.153	.170	.747	3780
313	.356	.296	.148	.800	.200	1.34	.426	.220	.219	1.00	1.04	.154	.171	.774	4000
325	.354	.295	.147	.796	.204	1.39	.419	.220	.253	1.15	1.04	.153	.170	.750	3830
349	.354	.295	.147	.796	.204	1.38	.419	.220	.253	1.15	1.04	.153	.170	.750	3700
Av.	.354	.295	.147	.797	.203	1.38	.420	.220	.234	1.06	1.04	.153	.170	.755	3830
295	.224	.447	.149	.820	.180	1.21	.452	.230	.235	1.02	0.87	.130	.148	.722	4930
318	.224	.447	.149	.820	.180	1.20	.454	.230	.235	1.02	0.87	.130	.148	.727	4790
331	.225	.450	.150	.825	.175	1.16	.462	.230	.238	1.03	0.87	.131	.149	.753	4970
332	.223	.447	.149	.819	.180	1.21	.452	.230	.235	1.02	0.87	.130	.148	.718	5050
Av.	.224	.448	.149	.821	.179	1.20	.455	.230	.236	1.02	0.87	.130	.148	.730	4685

SAND NO. 36

NOMINAL VALUES , C=.10, B = .30

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
344	.387	.297	.099	.783	.217	2.18	.315	.218	.208	.95	1.47	.146	.165	.676	1820
309	.392	.304	.101	.787	.213	2.03	.331	.218	.213	.98	1.46	.148	.167	.722	1710
320	.389	.299	.100	.788	.212	2.08	.324	.218	.210	.96	1.46	.147	.166	.707	1680
285	.386	.297	.099	.782	.218	2.18	.313	.218	.208	.95	1.47	.146	.164	.673	1735
Av.	.389	.299	.099	.785	.215	2.10	.322	.218	.210	.95	1.46	.147	.166	.694	1736
345	.376	.289	.096	.761	.239	2.47	.288	.218	.239	1.10	1.77	.170	.188	.715	1380
310	.384	.295	.098	.777	.223	2.26	.307	.218	.247	1.13	1.81	.174	.192	.785	1145
321	.378	.291	.097	.766	.234	2.40	.294	.218	.241	1.11	1.77	.171	.190	.734	1260
286	.378	.291	.097	.766	.234	2.41	.293	.218	.241	1.11	1.77	.171	.189	.731	1120
Av.	.379	.292	.097	.765	.235	2.38	.296	.218	.242	1.11	1.78	.172	.190	.741	1226
346	.367	.282	.094	.743	257	2.72	.269	.218	.270	1.24	2.06	.194	.212	.758	950
311	.382	.293	.098	.773	.227	2.31	.302	.218	.286	1.31	2.07	.202	.220	.894	1100
322	.384	.296	.099	.779	.221	2.24	.308	.218	.288	1.32	2.06	.203	.222	.918	935
287	.365	.281	.094	.740	.260	2.77	.265	.218	.269	1.23	2.06	.193	.211	.746	840
Av.	.374	.288	.096	.759	.241	2.51	.288	.218	.278	1.28	2.06	.198	.214	.829	931
347	.366	.281	.094	.741	.259	2.75	.267	.218	.308	1.41	2.36	.221	.239	.857	740
312	.376	.289	.097	.762	.238	2.46	.289	.218	.321	1.47	2.36	.228	.246	.963	660
323	.369	.284	.095	.748	.252	2.68	.272	.218	.312	1.43	2.36	.223	.241	.882	710
288	.380	.292	.097	.769	.231	2.36	.298	.218	.325	1.49	2.37	.230	.248	1.000	690
Av.	.373	.286	.096	.755	.245	2.56	.282	.218	.316	1.45	2.36	.226	.244	.926	700

SAND NO. 36

NOMINAL VALUES, C = .10, B = .45

Cyl. No.	a	b	c	d	v	$\frac{v}{c}$	$\frac{c}{v+c}$	w_{mo}	w_m	$\frac{w_m}{w_{mo}}$	$\frac{w_c}{c}$	w_c	w_{cx}	$\frac{w_c}{v}$	Unit Load
291	.289	.438	.097	.824	.176	1.80	.358	.217	.207	.95	1.19	.116	.136	.778	2650
314	.290	.439	.098	.827	.173	1.76	.362	.217	.207	.95	1.19	.116	.136	.792	2920
327	.290	.440	.098	.828	.172	1.75	.364	.217	.209	.96	1.20	.117	.136	.796	3150
334	.292	.443	.098	.833	.167	1.69	.372	.217	.210	.97	1.19	.117	.137	.826	3540
Av.	.290	.440	.098	.828	.172	1.75	.364	.217	.208	.96	1.19	.116	.136	.798	3065
292	.287	.435	.097	.819	.181	1.88	.348	.217	.244	1.12	1.43	.138	.158	.763	2000
315	.288	.436	.097	.821	1179	1.84	.353	.217	.247	1.14	1.43	.139	.158	.782	2150
328	.287	.435	.097	.819	.181	1.93	.342	.217	.244	1.12	1.43	.138	.158	.742	2230
Av.	.287	.435	.097	.820	.180	1.88	.348	.217	.245	1.13	1.43	.138	.158	.762	2127
293	.283	.429	.095	.807	.193	2.03	.331	.217	.278	1.28	1.67	.159	.178	.824	1590
316	.281	.426	.095	.802	.198	2.01	.332	.217	.275	1.27	1.67	.158	.177	.832	1610
329	.282	.427	.095	.804	.196	2.06	.327	.217	.278	1.28	1.66	.158	.178	.807	1480
Av.	.282	.427	.095	.804	.196	2.03	.330	.217	.277	1.28	1.67	.158	.178	.821	1560
294	.283	.429	.095	.807	.193	2.03	.331	.217	.319	1.47	1.91	.182	.201	.944	1100
317	.283	.429	.095	.807	.193	2.03	.331	.217	.319	1.47	1.91	.182	.201	.944	1220
330	.282	.427	.095	.804	.196	2.06	.326	.217	.316	1.46	1.91	.181	.200	.924	1044
Av.	.283	.428	.095	.806	.194	2.04	.329	.217	.318	1.47	1.91	.182	.201	.937	1121

VI. DISCUSSION OF CONCRETES

16. Water Content.- The water at basic water content required by different sands is not the same. In the same sand it varies with the ratio $\frac{a}{c}$. The water required at basic water content, by the sands used in this set of tests is shown by a curve on the diagram which gives the voids-mortar data. Part of these data are in the thesis by Mr. M. C. Nichols. These water content curves for the various sands have the same general shape. They differ in the low values of c or the high values of $\frac{a}{c}$, some of them sloping up and others down. At the high values of $\frac{a}{c}$ the point at which minimum volume in the mortar occurs is very hard to determine with accuracy. The volume of the mortar does not change much with additional water. In sands in which the amount of water at large values of $\frac{a}{c}$ is hard to determine, the voids in the mortar are large and they do not become filled with water until the water content ratio is very high. A comparison of the mortar curves shows that the water curve is very similar in shape to the voids curve. In the fine sand the voids are not so nearly filled with water as they are in the coarse sand. This tends to make the amount of water required by the two sands more nearly equal than the voids would indicate.

The effect of this difference in amount of water on the strength of the concrete can be shown either on the cement-space ratio curves or the water-cement ratio curves. The cement-space ratio curves for the natural sands are in Mr. Nichols' thesis. The water-cement ratio for the natural sands are in this thesis.

The water-cementratio will be used in the discussion of the effect of water. If two sands are used in the making of concretes, one fine and one coarse, the ratio of the fine aggregate to the

coarse aggregate being the same in the two cases, and also the cement content, then that made with the fine sand will require more water per unit volume of concrete than the other and its strength will decrease an amount indicated by the water-cement ratio curve. The decrease would be the greatest with higher values of cement and the least with the lower values of cement as is seen from the curve. If less water is used with the fine sand, the strength values will fall off of the curve and will not show the increase expected from the curve. The same thing can be shown from the cement-space ratio curve. In this case, however, in the fine sand when not enough water is used, the strength is still indicated by the curve, although the position on the curve may be changed. On this account the cement-space ratio appears to give a closer relation with the strength than the water cement ratio.

No data were taken to show whether the basic water content gave the maximum strength. It is very probable that the maximum strength comes at a somewhat smaller water content ratio. The point of minimum volume is easy to determine and possible to duplicate, which gives it a great advantage as a point of reference.

17. Consistency of Mix.- The concrete of a given mix which has that amount of water that produces the maximum strength is generally a stiff and very unworkable mixture. In order to place concrete in reinforced members, more water must be added to give the concrete the requisite workability so that it may be worked around the reinforcement and into every part of the forms. The

additional water brings with it a decrease in the strength of the concrete. This decrease in strength has long been an observed fact, but the amount and cause of the decrease is still a much debated question. The addition of water to a mix does not change the materials in a unit volume of concrete very much. In sand No. 32 for c = .10 and b = .30, the addition of 20 per cent more water changed the density of the concrete from .752 to.743, while the average strength of the second concrete was only 87 per cent of the first. For c = .10 and b = .50, (using the same sand) the density changed from .814 to .810 with the addition of 20 per cent more water, and the strength of the second was 64 per cent of the first. In sand No. 31 for c = .10 and b = .30 the addition of 20 per cent more water changed the density from .792 to .775, while the strength of the second was 63.7 per cent of the first. For c = .10 and b = .50 and the same sand, the density changed from .854 to .826, and the strength of the second was 65.4 per cent of the first. The variation in strength with the addition of water does not follow any simple law. Neither do different sands act the same.

Several functions have been plotted to show the relation between the function and the strength of the concrete. The best two are the cement-space ratio and the water cement ratio. The cement-space ratio equals the absolute volume of the cement divided by the sum of the voids and the absolute volume of the cement. The average result of each set of test specimens has been plotted with both of these functions.

For the specimens having water contents near the basic water content the resulting points fit both curves well. Apparently they come a little closer to the water-cement ratio curve but this is due more to the shape of the curve and the scale to which it is plotted. In using the curves to design mixes this apparent advantage would become a disadvantage because the strength could not be predetermined as accurately as the curve indicates.

In the wet mixes the points do not follow the cement-space ratio curve so closely. This happens especially with rich mixes and large values of b . The rich mixes with large values of b have the greater strength and therefore the points come where the curve is steepest.

When a concrete is made with a small amount of water, there must be a film of water around the particles which probably acts as a lubricant in mixing and placing concrete. When the concrete is placed and begins to set, some of this water must be taken up in the hydration of the cement and in the absorption by the aggregate, the latter bringing the cement and aggregate into closer contact, thus probably helping the adhesive action. It may be that the particles of cement swell somewhat in setting and thus help to bring this about. Concrete generally shrinks somewhat in setting and it may be that this action is enough to bring the particles into very close contact.

With concrete made with a high water-content ratio, there must be more water in the mix than can be taken care of by absorption and hydration of cement. There is more shrinkage in the wet mix, but even after this shrinkage has taken place

the mix is still very wet. A film of water must remain around the particle for some time which prohibits a close contact between the aggregate particles and cement particles. It may be that the basic water content as used is a little wetter than is the practice for normal consistency in some laboratories.

The water-cement ratio relation seems to fit the wet mixes very well. The points come in a very close band bordering the curve. The place in which the points fit this curve better than the cement-space ratio curve is on a steep part of the curve. This partly explains why the values fit the curve better. Even here the wet mixes are in close agreement with the curve for dry mixes.

On comparing this curve for the water-cement ratio with the curve given in Bulletin 1 of Lewis Institute, it is seen that the curve given here is much lower. This seems to indicate that possibly the same function of water-cement ratio will not apply to all tests. The cement-space ratio curve given is one that was chosen to fit the results of other tests. It does not exactly fit the results in this thesis but the disagreement is small.

It may be found desirable to change the constants in one or both of the equations for the two curves. The results with the artificially graded sands seem to be a little low throughout the whole range. This sand had considerable fine material in it. In order to get enough of the fine material the larger sizes were ground in a ball mill. The ground material was then screened to get the desired sizes of small particles. This sand may have been weakened by the grinding.

18. Method of Design.- The method used in designing the test specimens gave satisfactory results. The mix was not intended to give any particular strength. The quantities were calculated so as to give a known volume of concrete at basic water content only. For mixes with higher water contents the same quantities of materials were used as in the basic water content mix except that the water was increased by a certain per cent of that used before. This decreased the amount of materials (including the cement) in a unit volume of concrete somewhat, due to the bulking with the increased water used. The method could have been used to determine the necessary amount of materials to give a certain volume of concrete at the higher water-content ratio. For the same cement-content, the amount of fine or coarse aggregate per unit volume of concrete would have been changed from that used at basic water content. For this set of tests there seemed to be no especial advantage in keeping the volume of concrete the same.

For the specimens intended to have basic water content, the variation of the water content from the value desired was greater than the variation in the quantities of the other ingredients. The value for the basic water content was obtained from the mortar tests. The mortar test of the concretes, which are reported in this thesis, were made among the first mortar tests. The increments of water used did not locate the basic water content accurately. In the last mortar tests this trouble was eliminated. The voids in the mortar seemed to be much easier to determine than the basic water content.

Using either the cement-space ratio relation or the water-

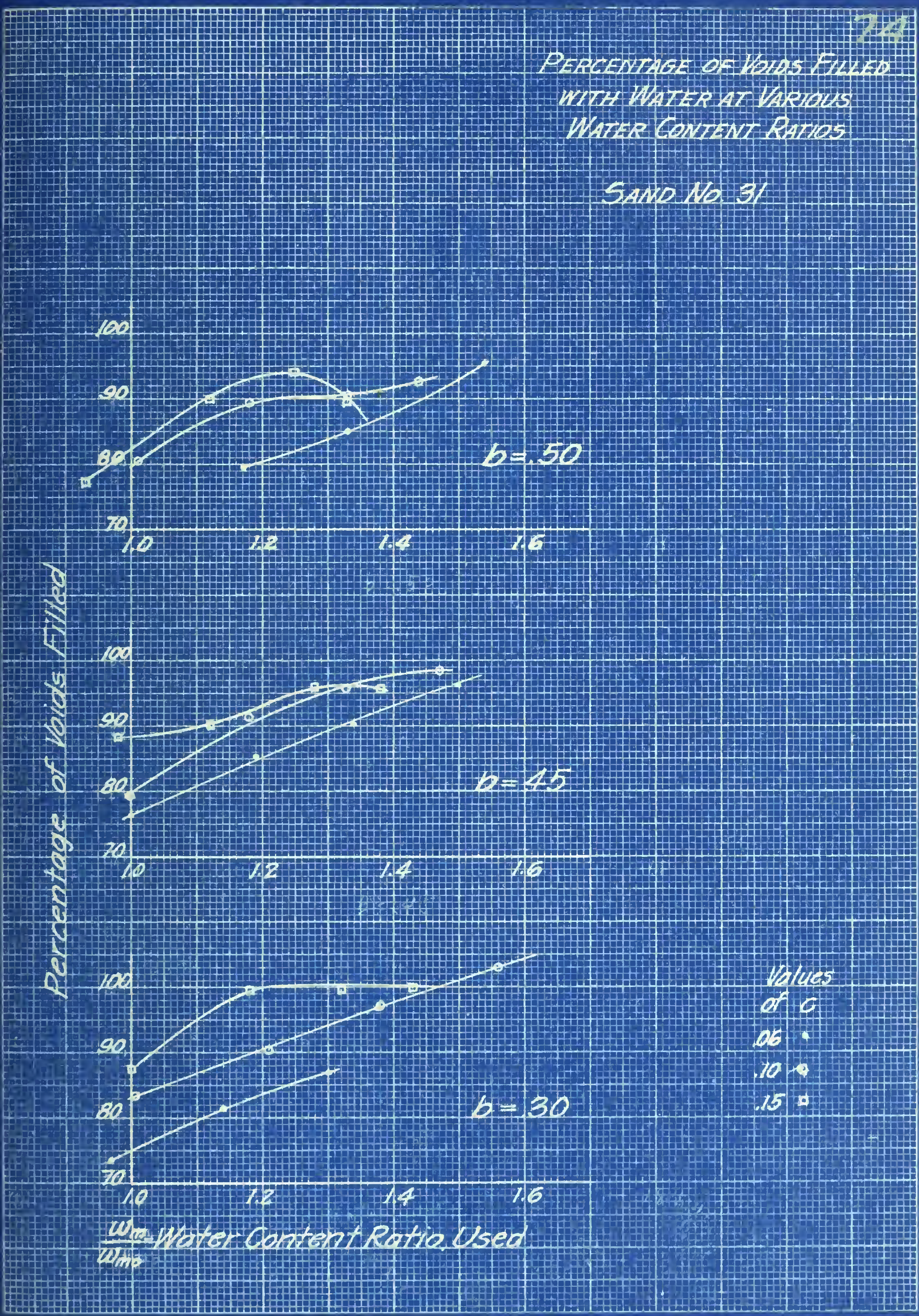
cement ratio relation this method could be used to design mixes of predetermined strength.

Conclusions.- From the study of these tests the following conclusions seem to be justifiable .

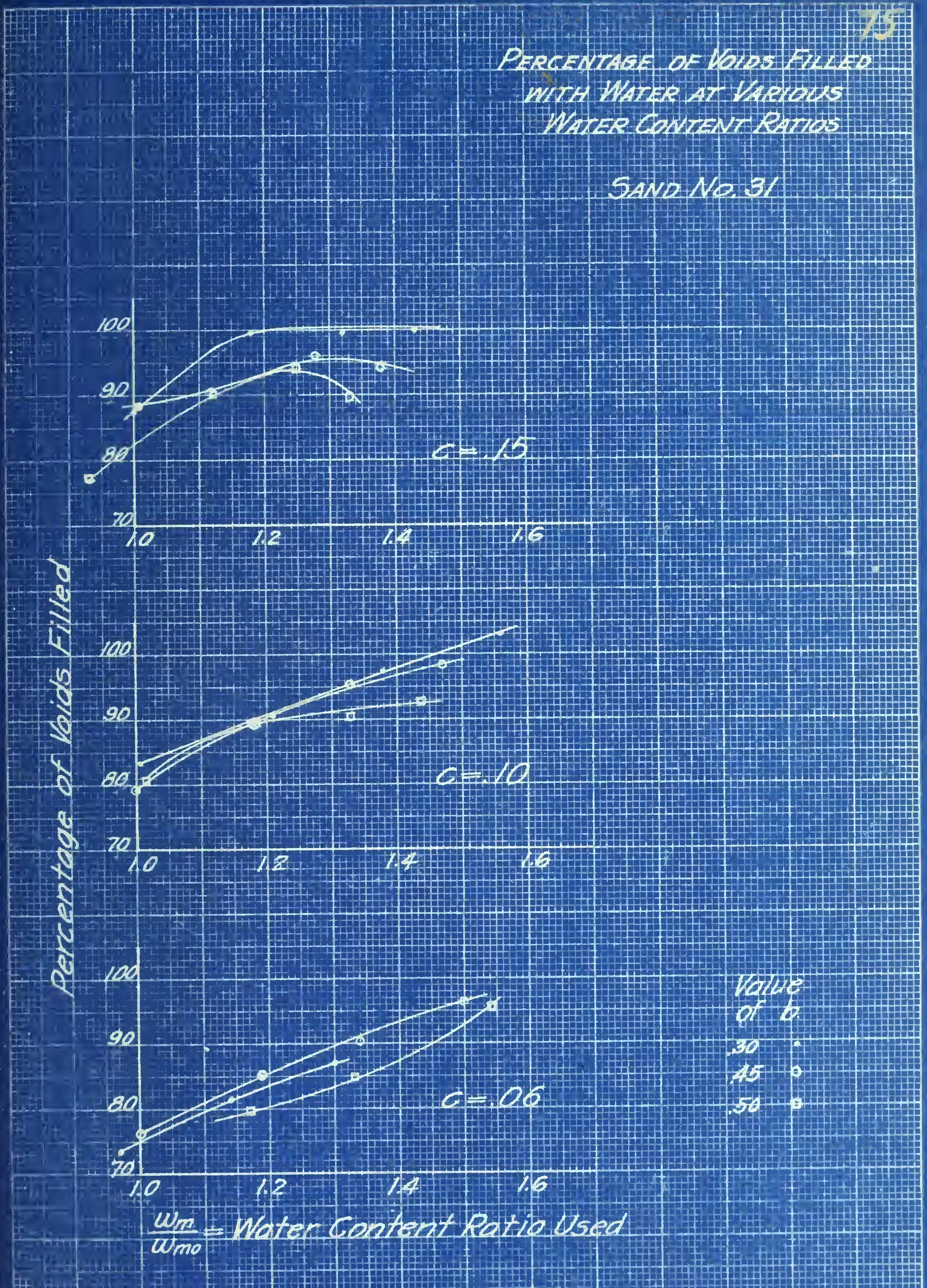
1. Water Content.- Different sands require different amounts of water at basic water content but this amount does not vary so much as the voids in the sand vary. The sands which require more water generally give lower strength but this is probably due to the voids in the sand rather than to the amount of water used. This variation in amount of water is not large in the majority of cases.

2. Consistency of mix.- The concrete falls off in strength with an increase in the amount of water used. The amount of this decrease is best measured by the cement-space ratio function up to a water content ratio of 1.4. This function also agrees with other tests. The water-cement ratio function also shows up well especially with the wet mixes. It is not certain that the relation obtained with this function as shown in the plotted results will agree with other tests. With a given sand it can be used to predetermine the strength of wet mixes.

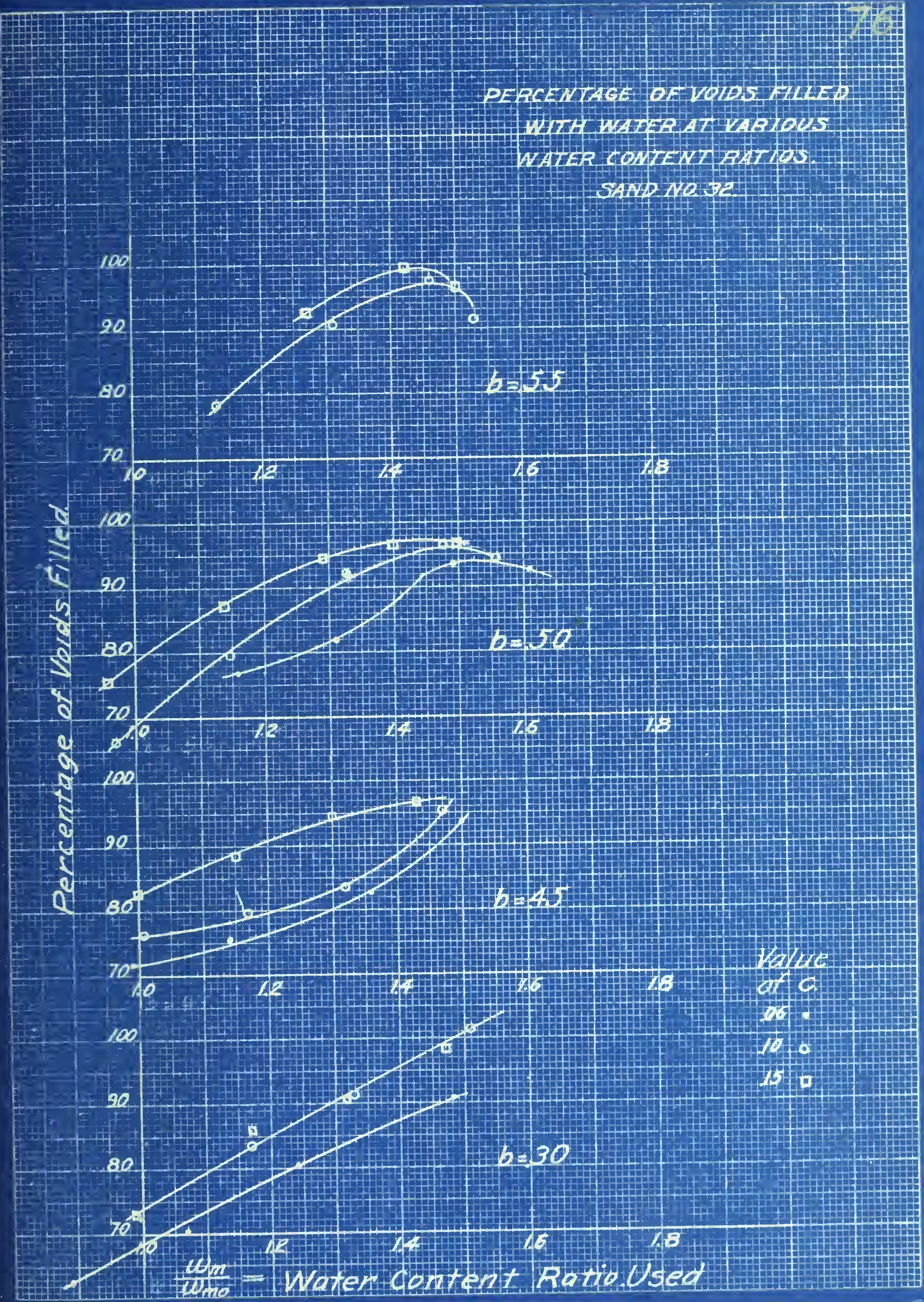
3. Method of Design.- The method of design used gives a satisfactory method of predetermining the amount of materials in a concrete mix. The same method could be used to design mixes of predetermined strength. It is especially useful in estimating the probable strengths of concretes made with different sands, in the absence of compression tests.

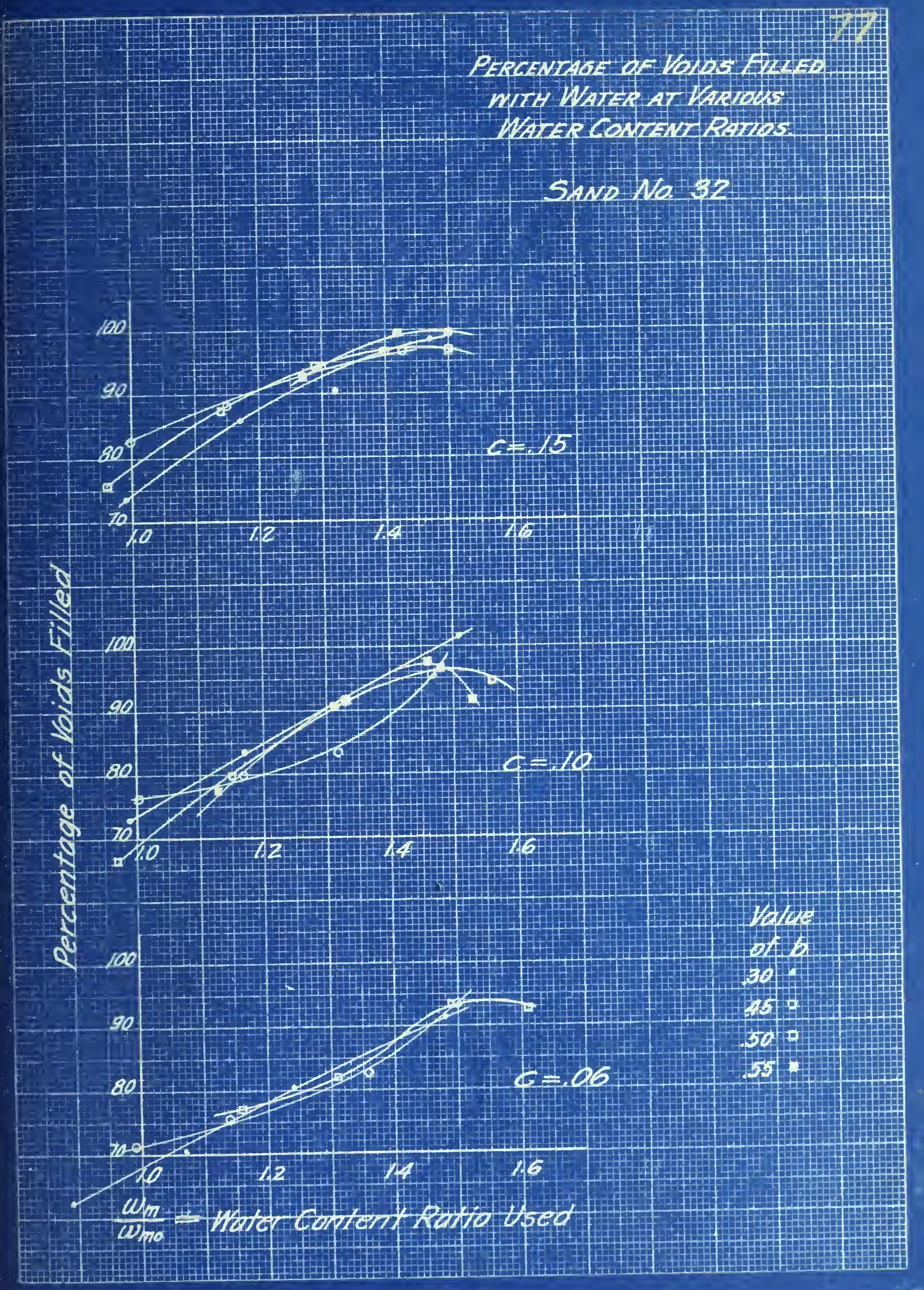


74
PERCENTAGE OF VOIDS FILLED WITH WATER AT VARIOUS WATER CONTENT RATIOS
SAND No. 31
Percentage of Voids Filled
100
90
80
70
1.0
1.2
1.4
1.6
b=.50
b=.45
b=.30
Values of c
.06
.10
.15
$\frac{W_m}{W_{mo}}$ - Water Content Ratio Used



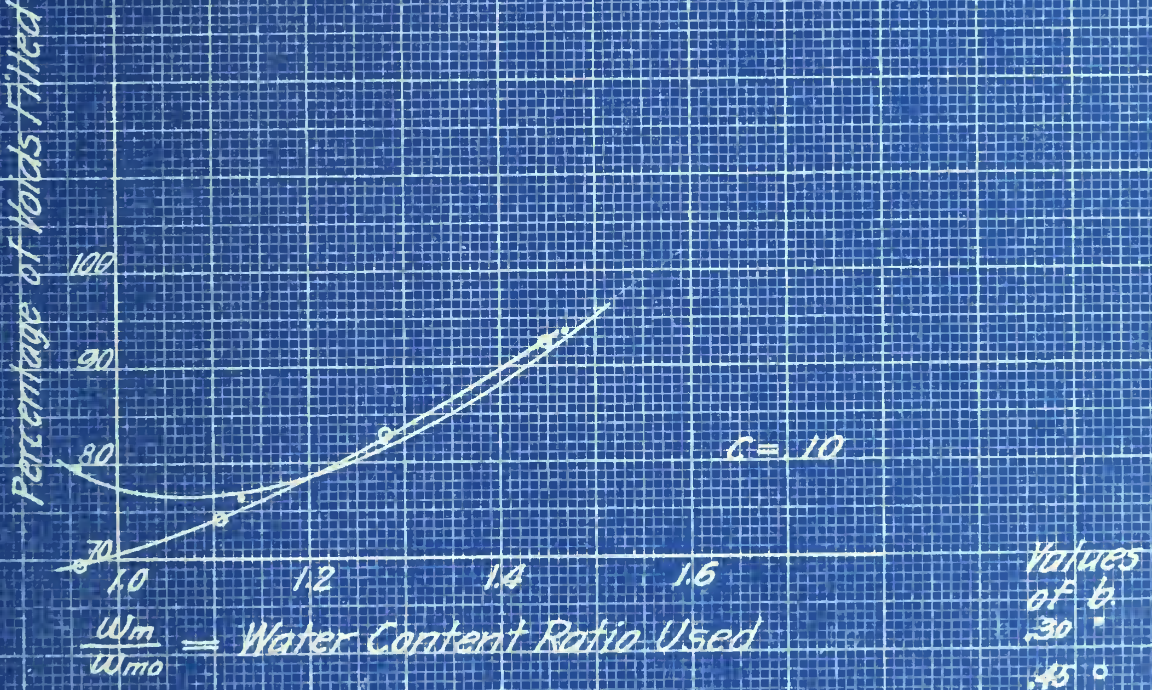
PERCENTAGE OF VOIDS FILLED WITH WATER AT VARIOUS WATER CONTENT RATIOS
SAND NO. 31
C = .15
C = .10
C = .06
100
90
80
70
1.0
1.2
1.4
1.6
Percentage of Voids Filled
Value of b
.30
.45
.50
$\frac{W_m}{W_{mo}}$ = Water Content Ratio Used


PERCENTAGE OF VOIDS FILLED
WITH WATER AT VARIOUS
WATER CONTENT RATIOS.
SAND NO. 32.
Percentage of Voids Filled
100
90
80
70
1.0
1.2
1.4
1.6
1.8
b=55
b=50
b=45
b=30
Value
of C.
.06
.10
.15
$\frac{\omega_m}{\omega_{mo}}$ = Water Content Ratio Used


PERCENTAGE OF VOIDS FILLED
WITH WATER AT VARIOUS
WATER CONTENT RATIOS
SAND No. 32
Percentage of Voids Filled
c=.15
c=.10
c=.06
100
90
80
70
1.0
1.2
1.4
1.6
Value
of b
.30
.45
.50
.55
Wm/Wmo = Water Content Ratio Used

PERCENTAGE OF VOIDS FILLED WITH WATER AT VARIOUS WATER CONTENT RATIOS

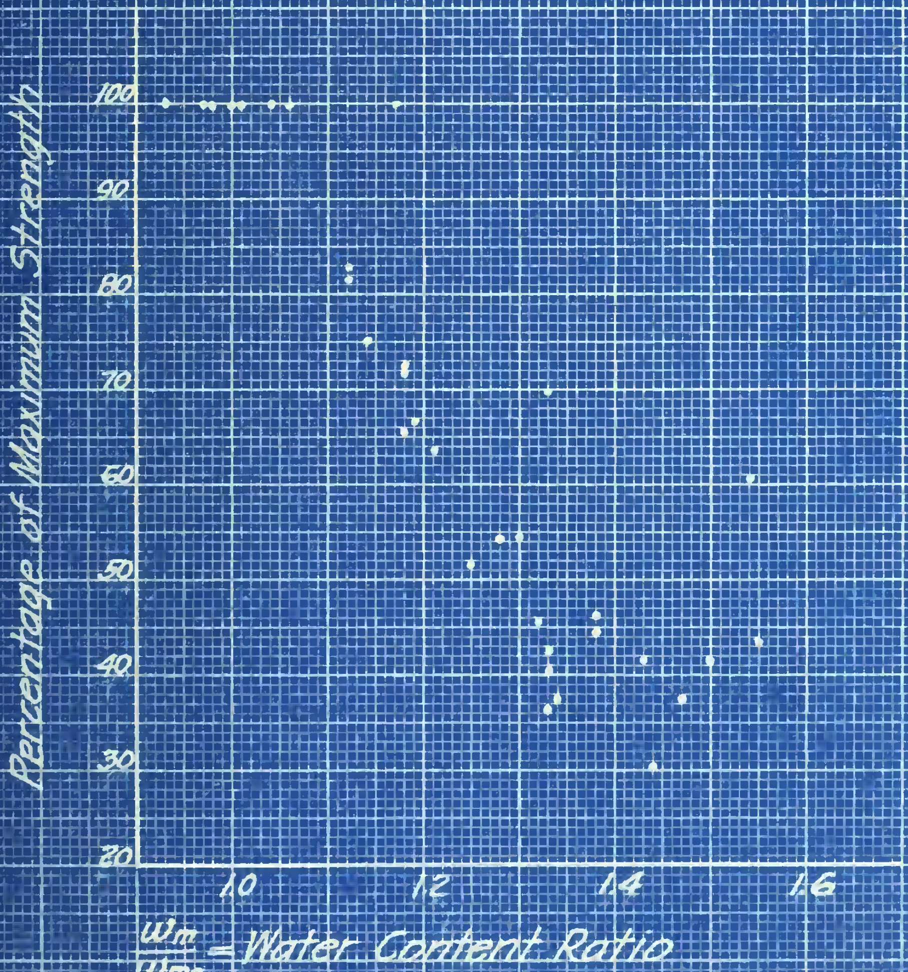
SAND NO. 36



CHANGE IN STRENGTH WITH VARIATIONS IN THE WATER CONTENT RATIO

ALL CONCRETE MIXES

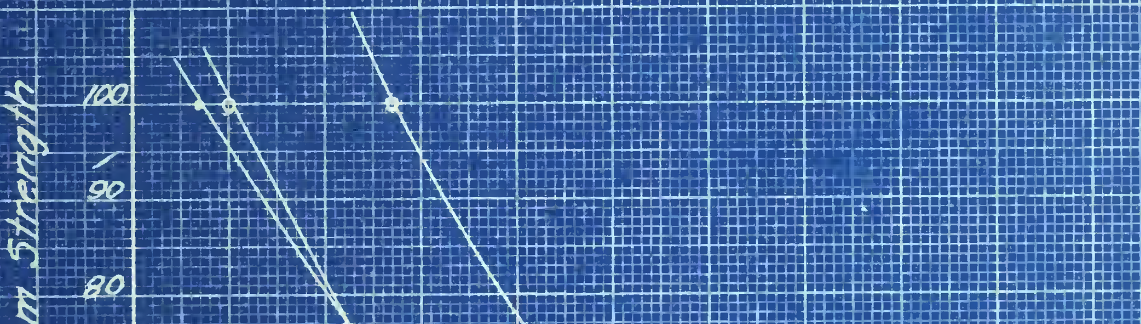
SAND No. 31.



8C

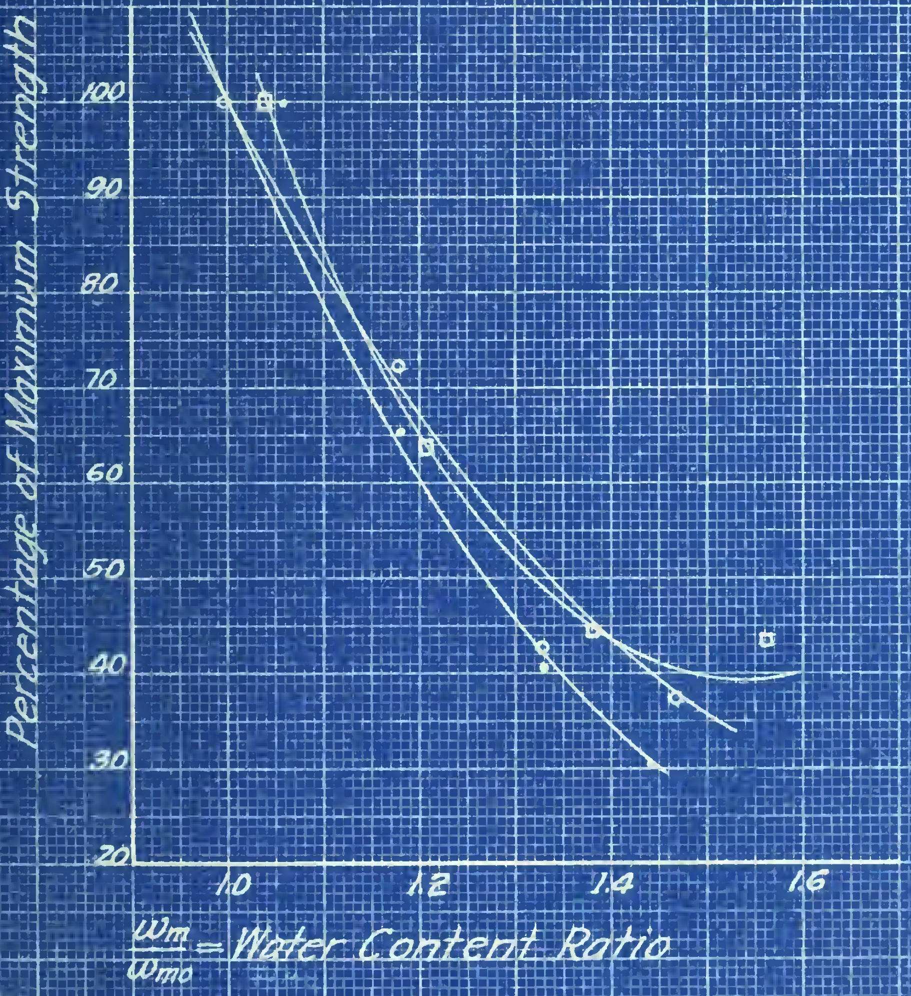
CHANGE IN STRENGTH WITH VARIATIONS IN THE WATER CONTENT RATIO

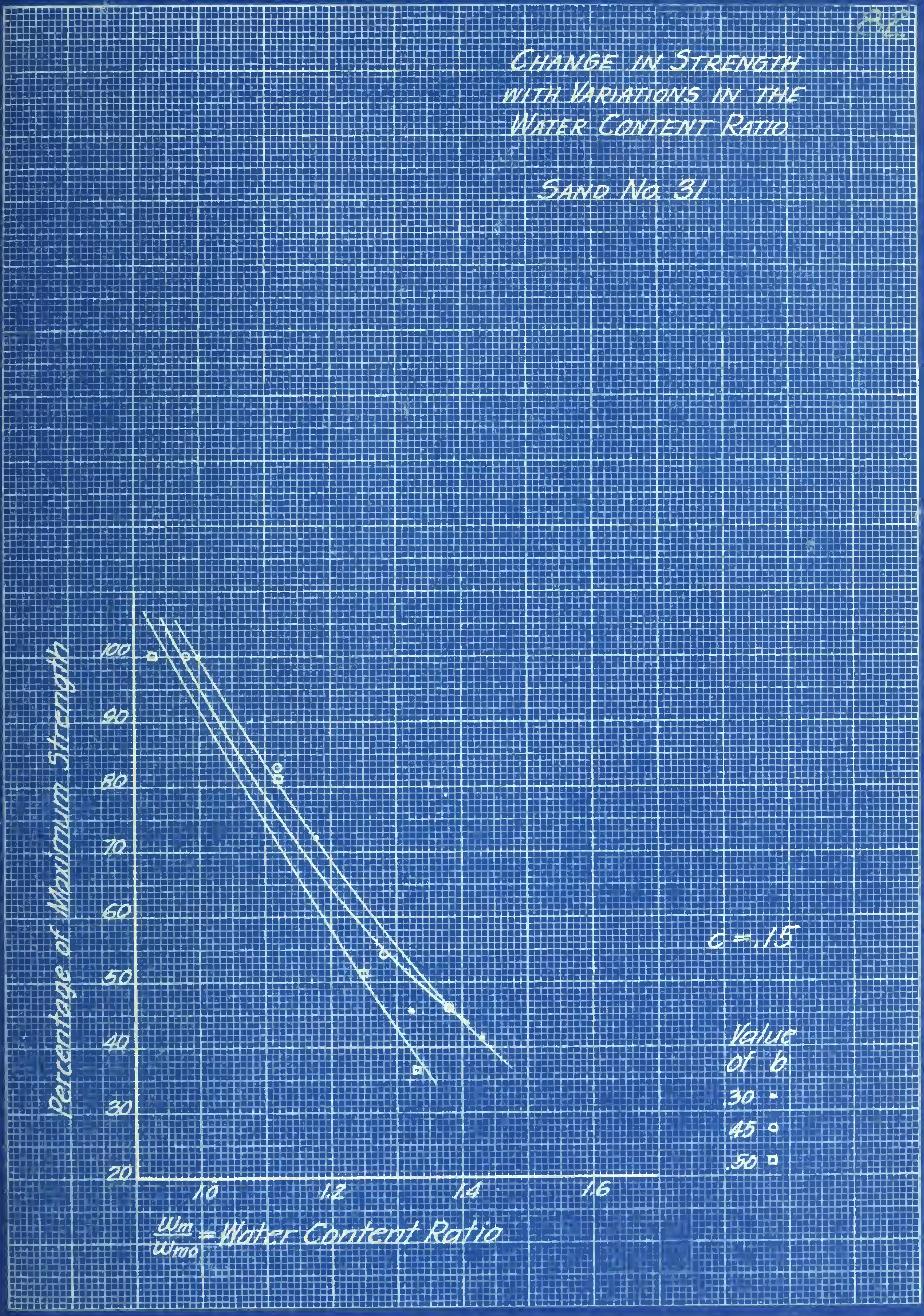
SAND NO. 31



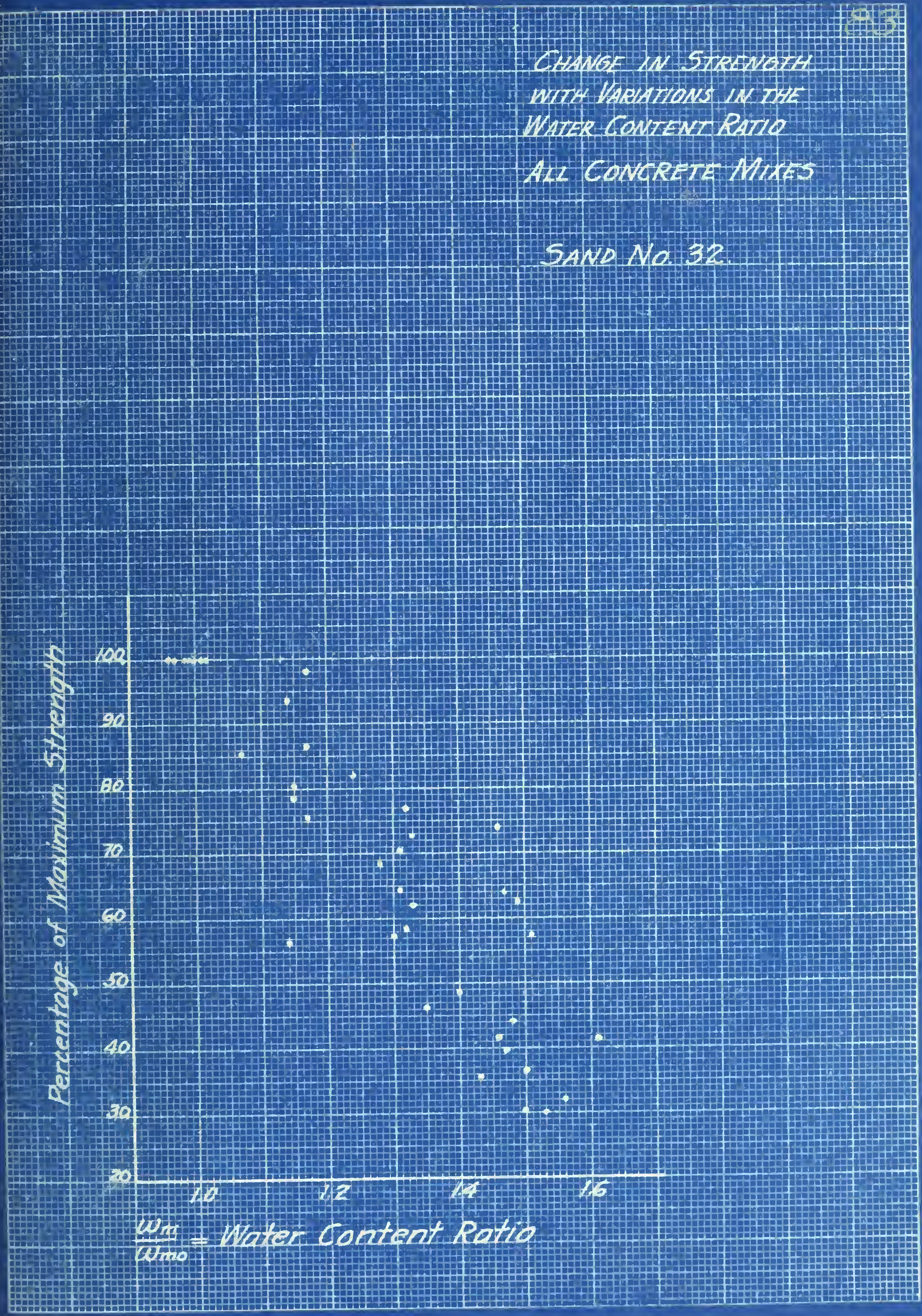
CHANGE IN STRENGTH WITH VARIATIONS IN THE WATER CONTENT RATIO

SAND NO. 31.





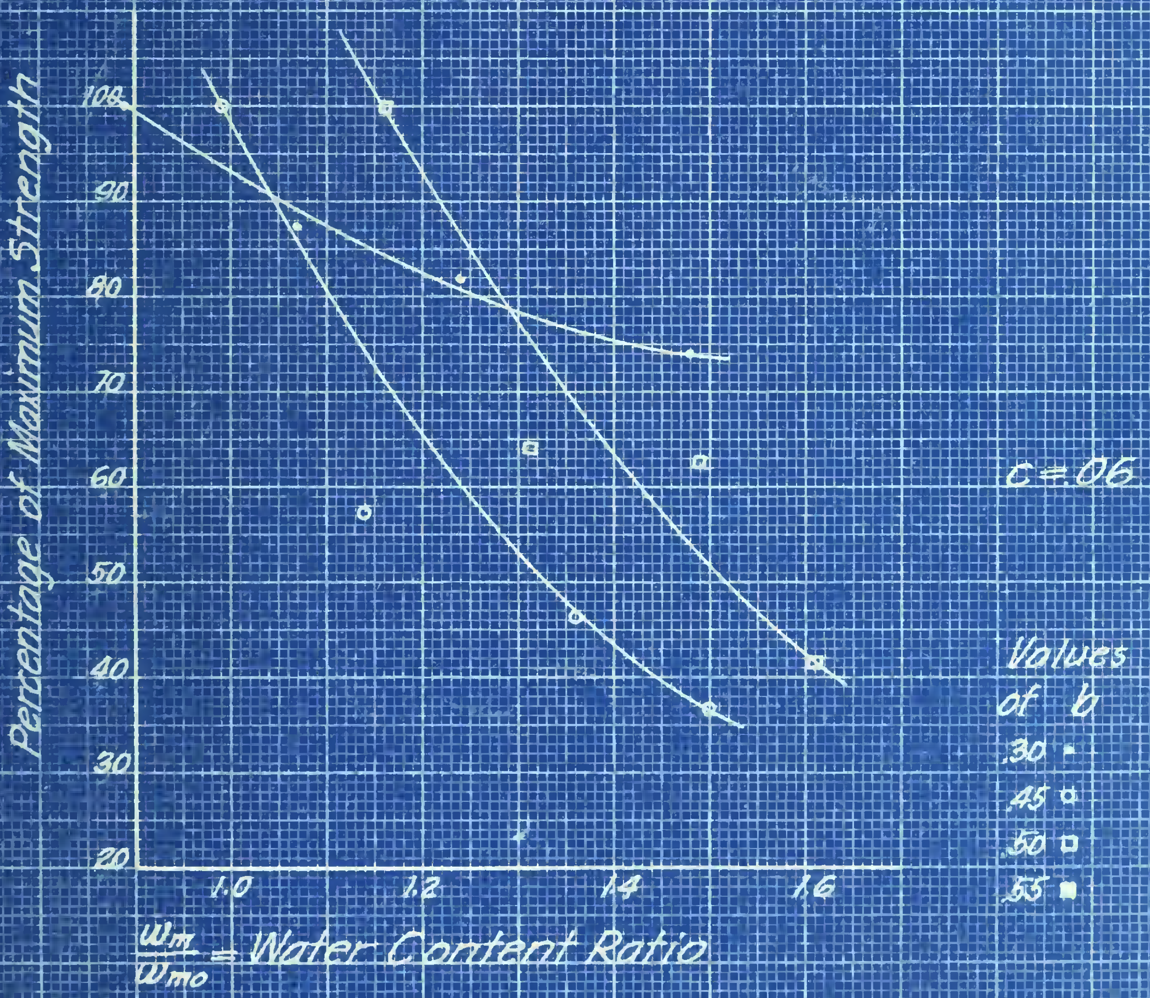
CHANGE IN STRENGTH
WITH VARIATIONS IN THE
WATER CONTENT RATIO
SAND No. 31
c = .15
Value of b
.30
.45
.50
Percentage of Maximum Strength
100
90
80
70
60
50
40
30
20
1.0
1.2
1.4
1.6
$\frac{W_m}{W_{mo}}$ = Water Content Ratio

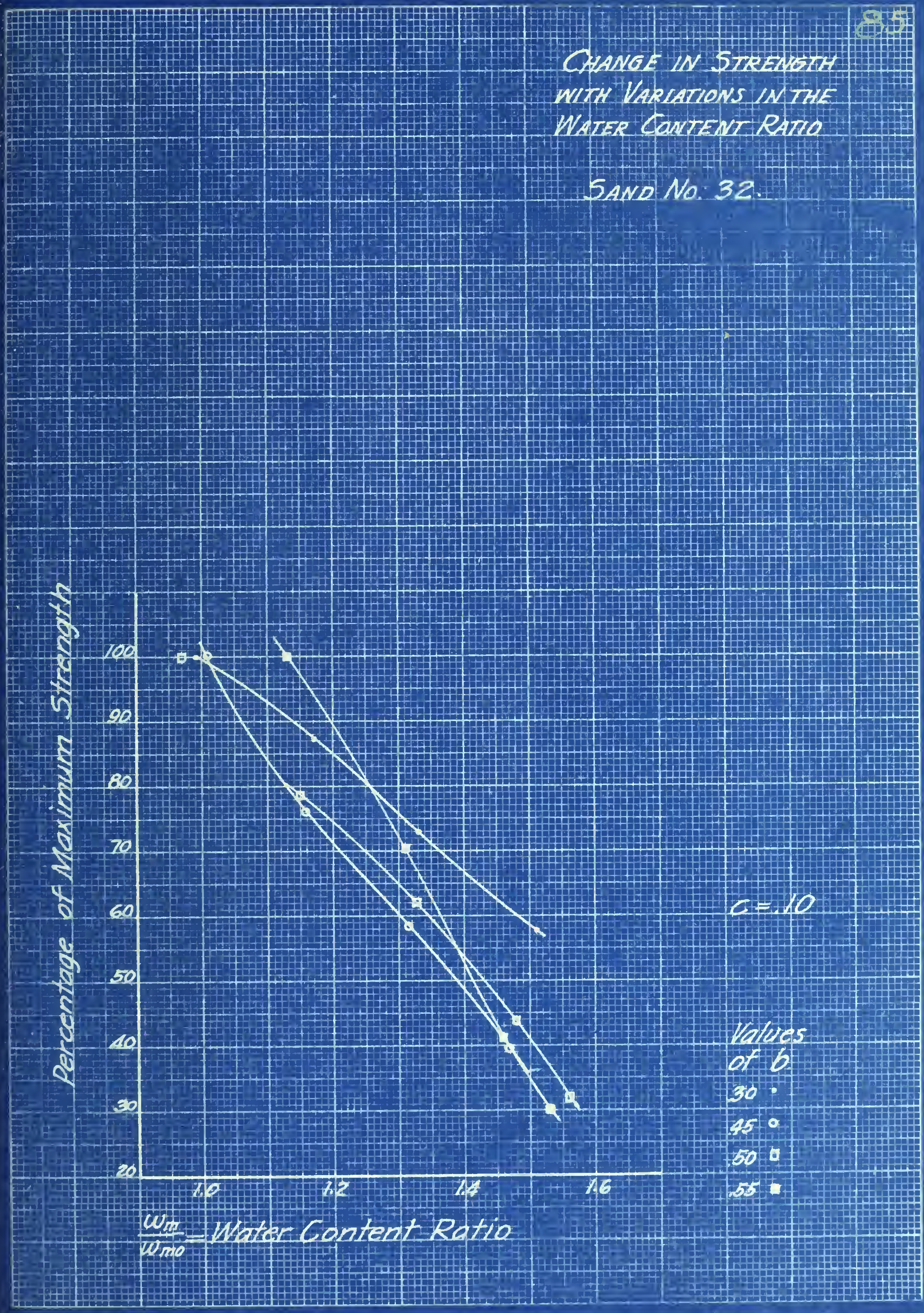


CHANGE IN STRENGTH
WITH VARIATIONS IN THE
WATER CONTENT RATIO
ALL CONCRETE MIXES
SAND No 32.
Percentage of Maximum Strength
100
90
80
70
60
50
40
30
20
1.0
1.2
1.4
1.6
$\frac{W_m}{W_{mo}}$ = Water Content Ratio

CHANGE IN STRENGTH
WITH VARIATIONS IN THE
WATER CONTENT RATIO

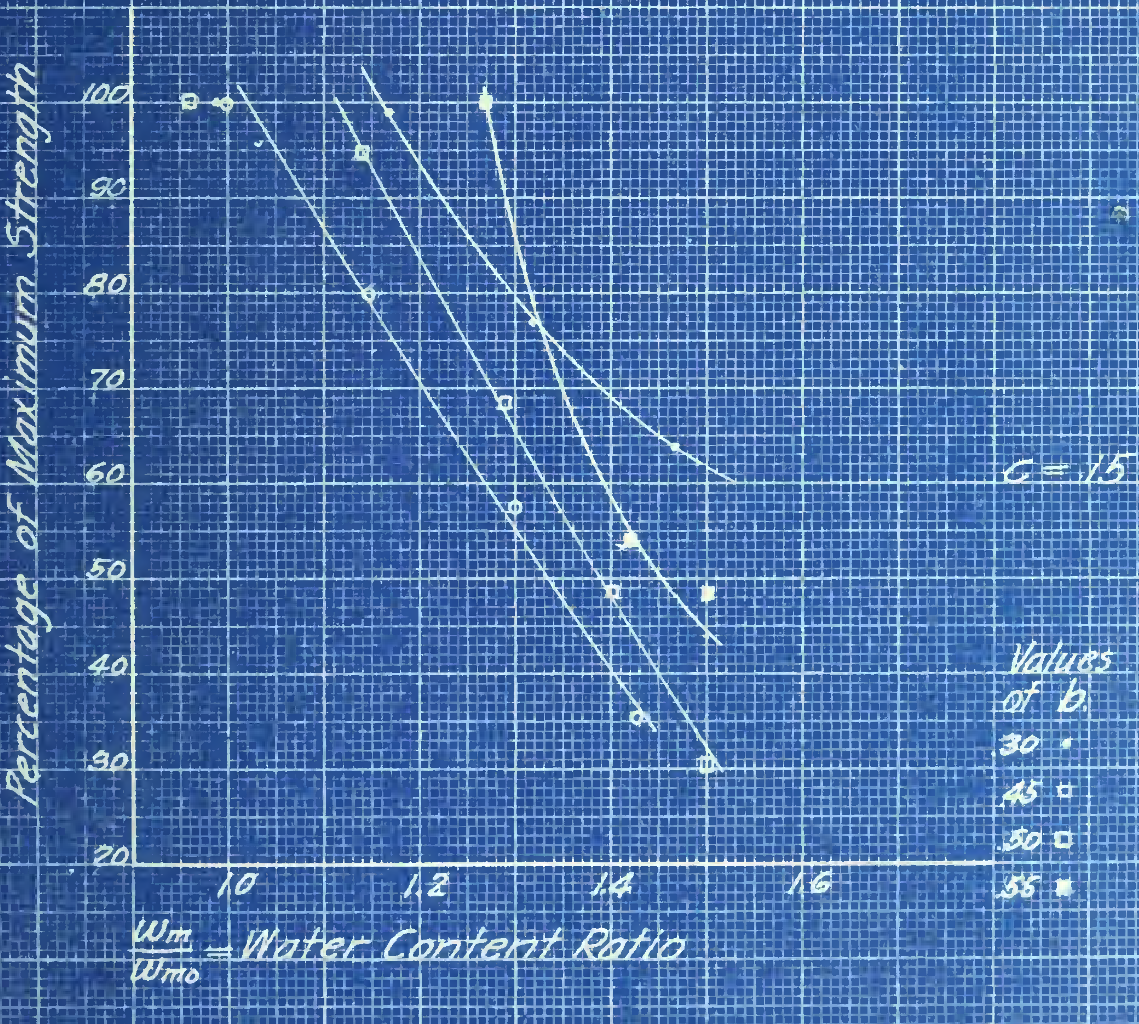
SAND NO. 32

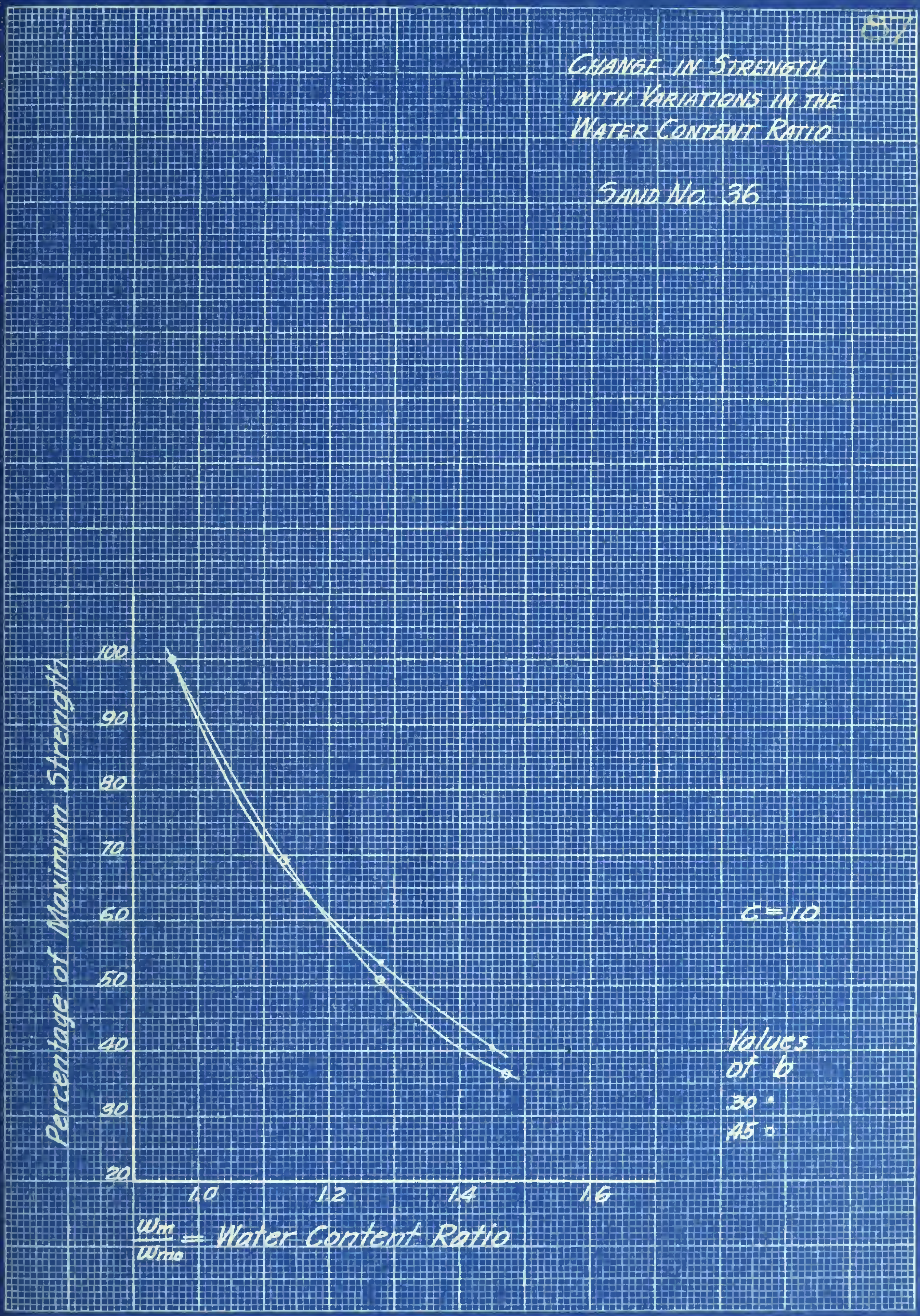


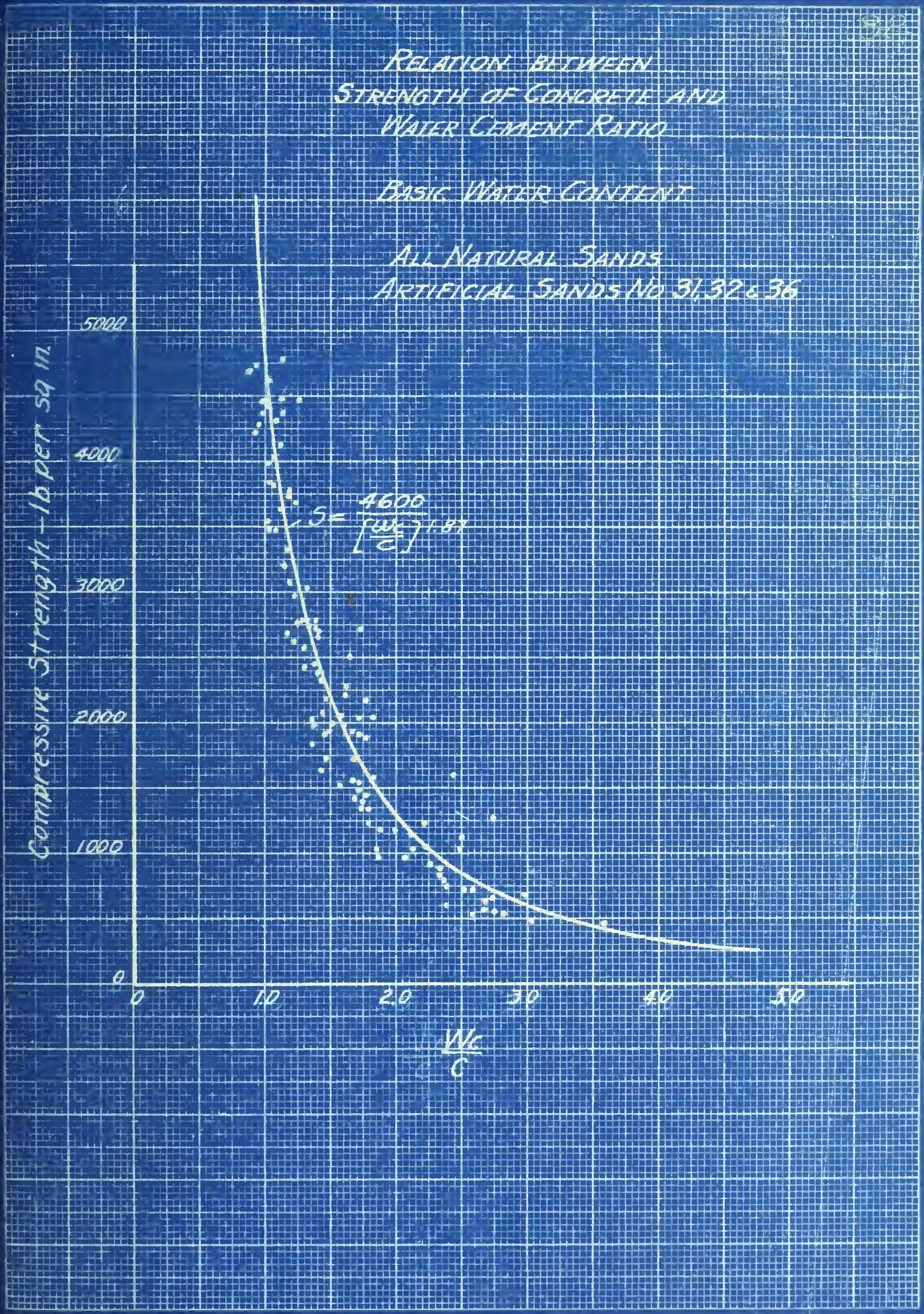

CHANGE IN STRENGTH
WITH VARIATIONS IN THE
WATER CONTENT RATIO
SAND NO. 32.
Percentage of Maximum Strength
100
90
80
70
60
50
40
30
20
1.0
1.2
1.4
1.6
$\frac{W_m}{W_{mo}}$ – Water Content Ratio
c = .10
Values
of b
.30
.45
.50
.55

CHANGE IN STRENGTH
WITH VARIATIONS IN THE
WATER CONTENT RATIO

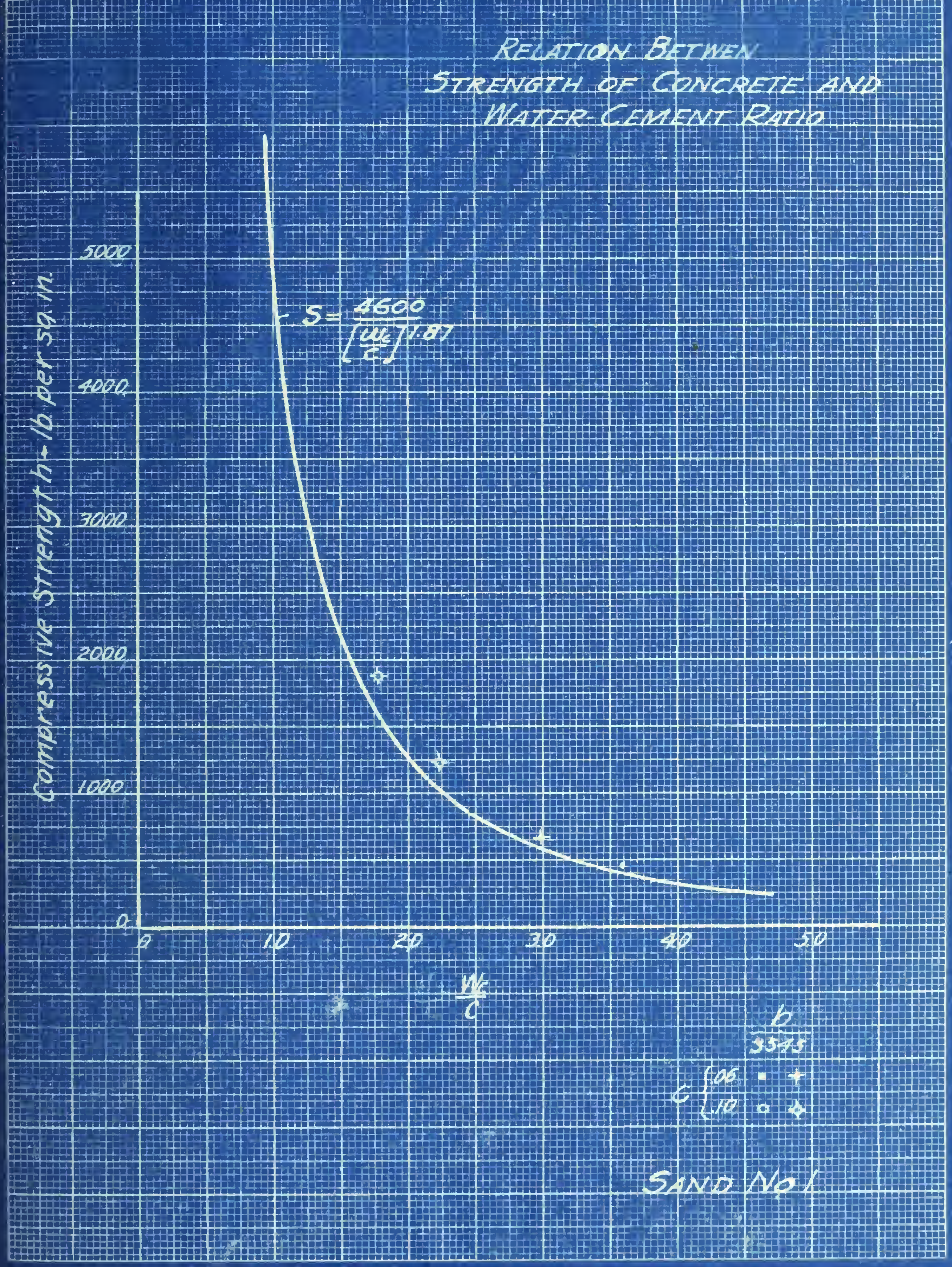
SAND NO. 32

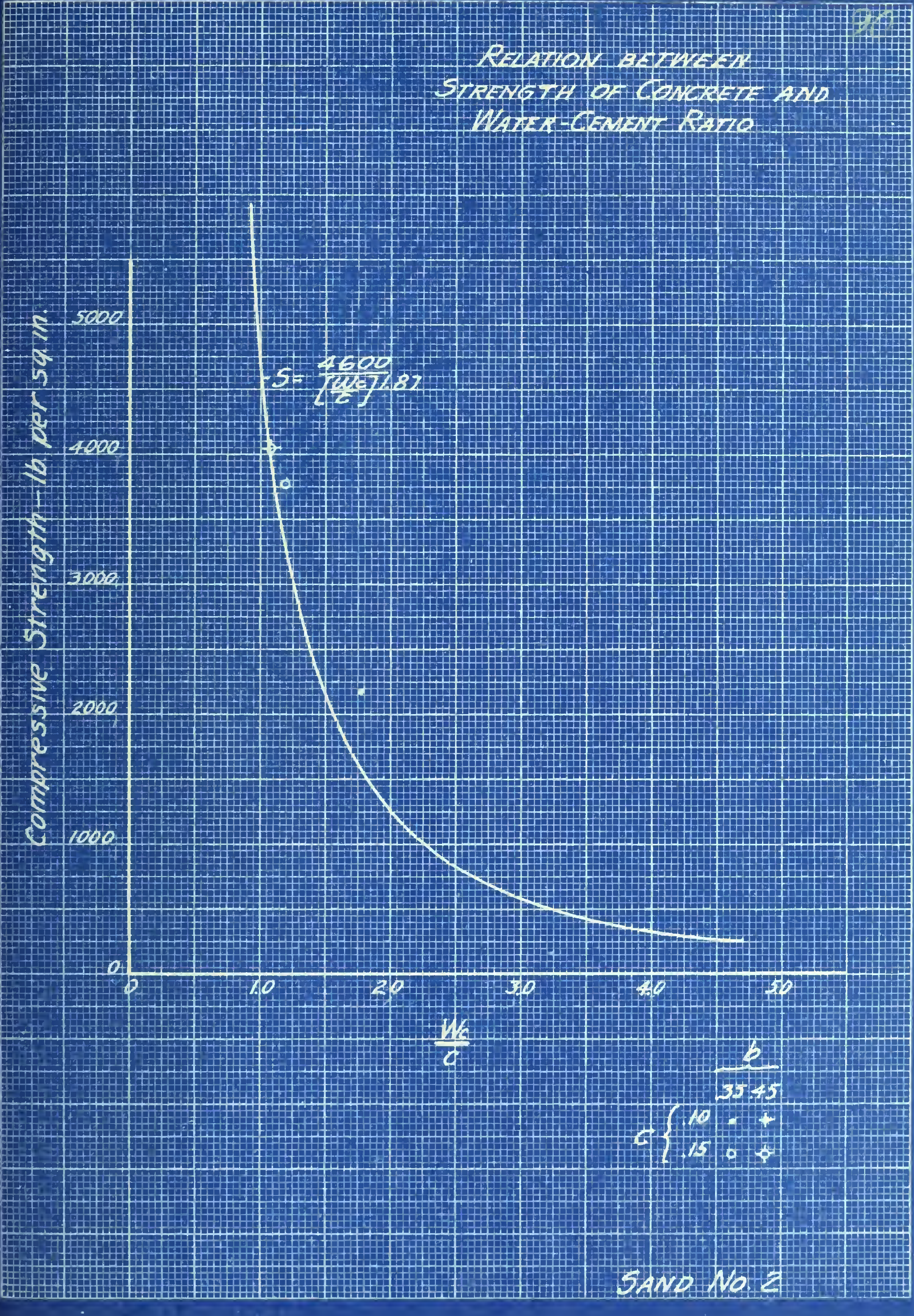



87
CHANGE IN STRENGTH
WITH VARIATIONS IN THE
WATER CONTENT RATIO
SAND NO. 36
C = 10
Values
of b
30 •
45 ○
Percentage of Maximum Strength
100
90
80
70
60
50
40
30
20
1.0
1.2
1.4
1.6
Wm/Wmo = Water Content Ratio

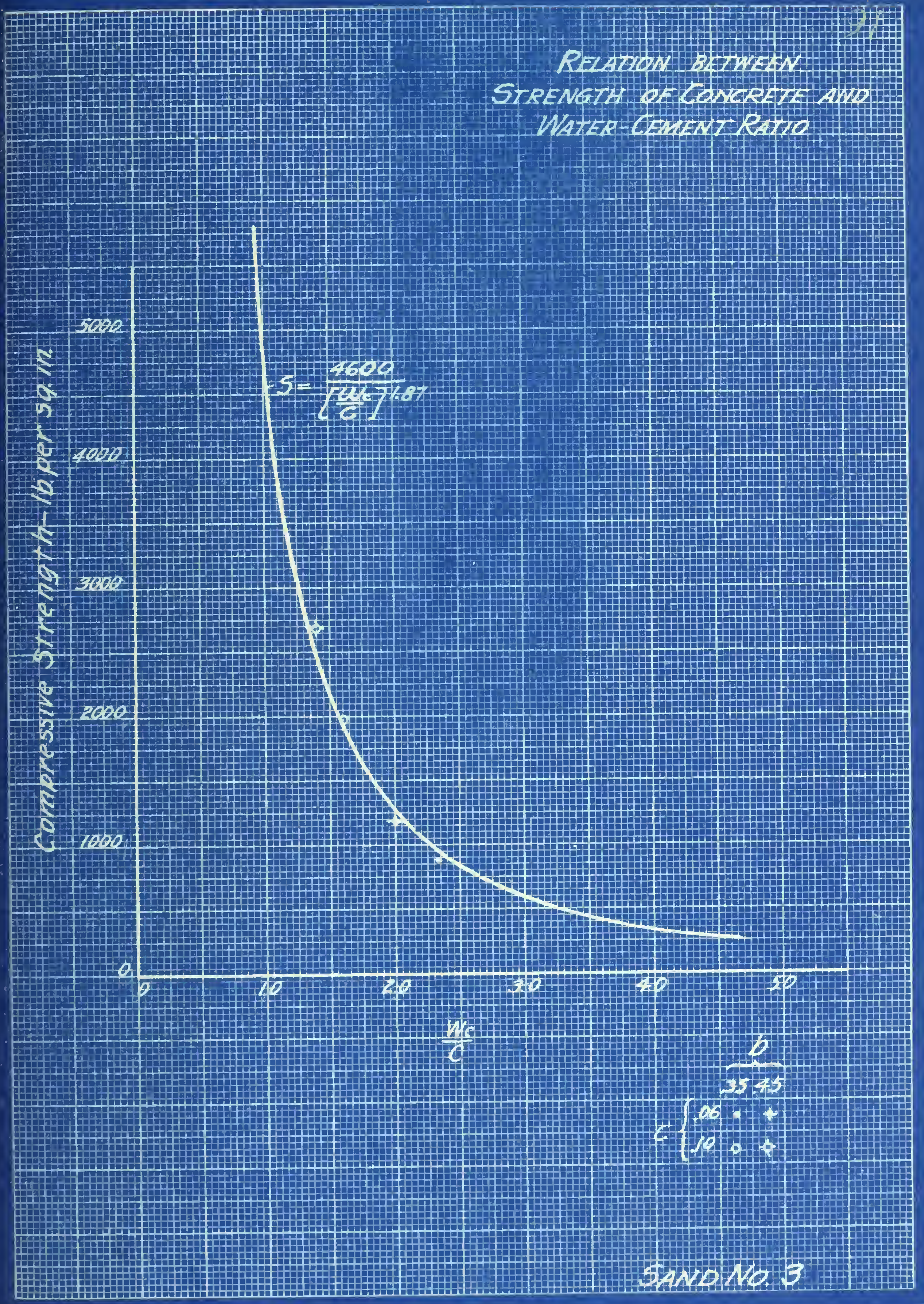


RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER CEMENT RATIO
BASIC WATER CONTENT
ALL NATURAL SANDS
ARTIFICIAL SANDS NO 31, 32 & 36
Compressive Strength - lb per sq in.
5000
4000
3000
2000
1000
0
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$


RELATION BETWEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
Compressive Strength - lb per sq. in.
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
b
35 45
C
.05
.10
SAND NO 1

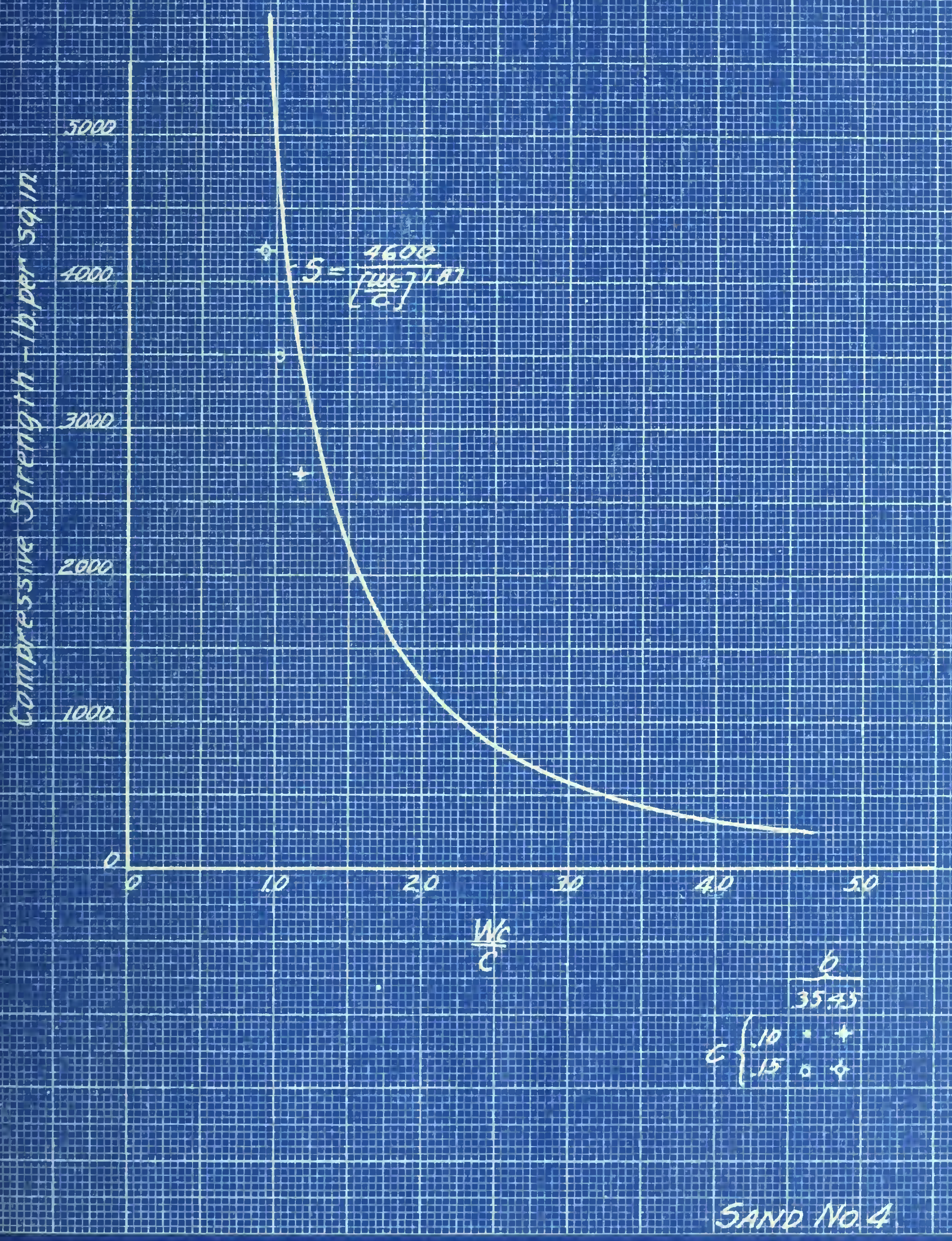


RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
Compressive Strength - lb per sq. in.
5000
4000
3000
2000
1000
0
$S = \frac{4600}{\left[\frac{W_c}{c}\right]^{1.87}}$
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{c}$
b
.35 .45
c
.10
.15
SAND No. 2

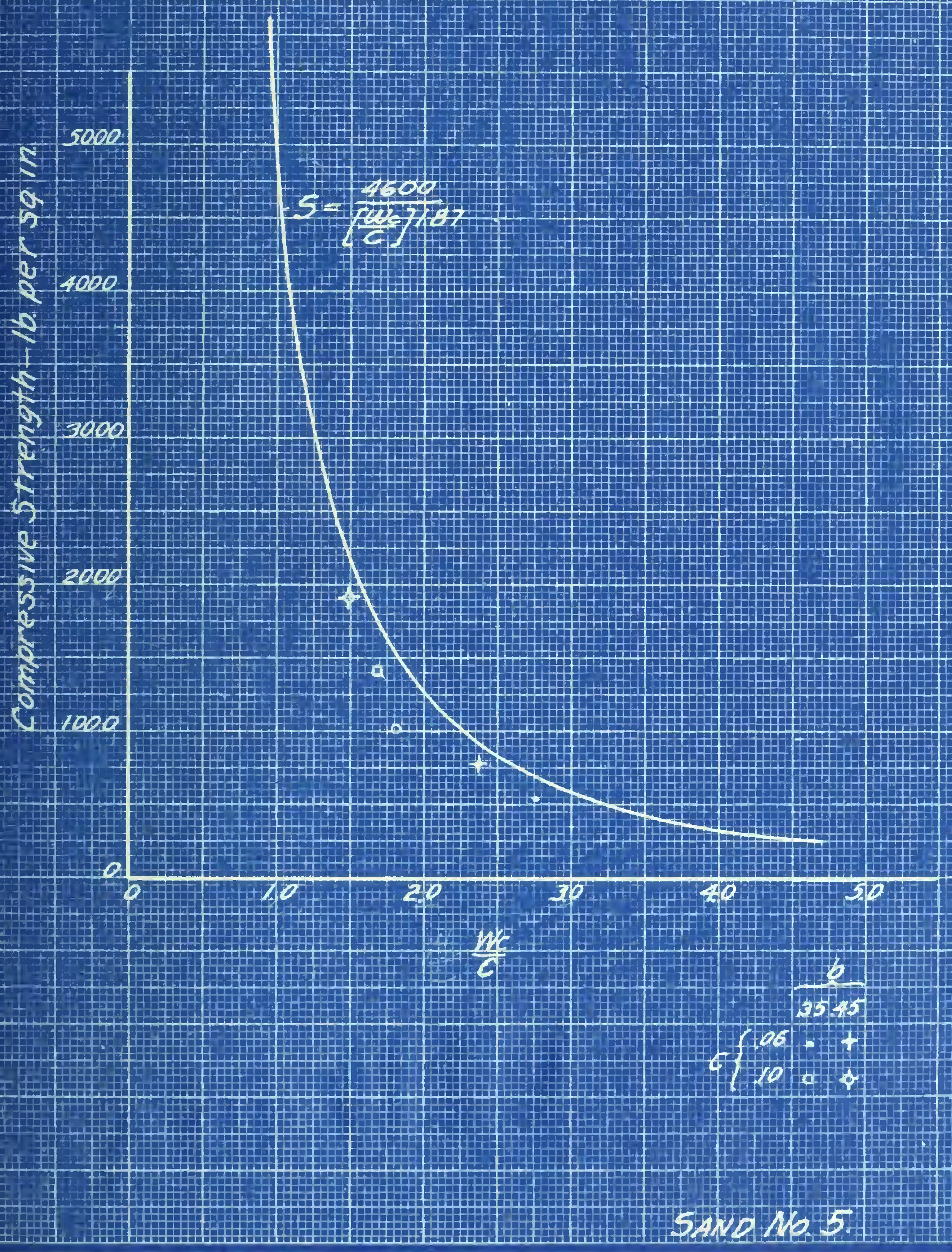


RELATION BETWEEN STRENGTH OF CONCRETE AND WATER-CEMENT RATIO
Compressive Strength - lb per sq. in.
5000
4000
3000
2000
1000
0
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
b
.35 .45
c .06
.10
SAND NO. 3

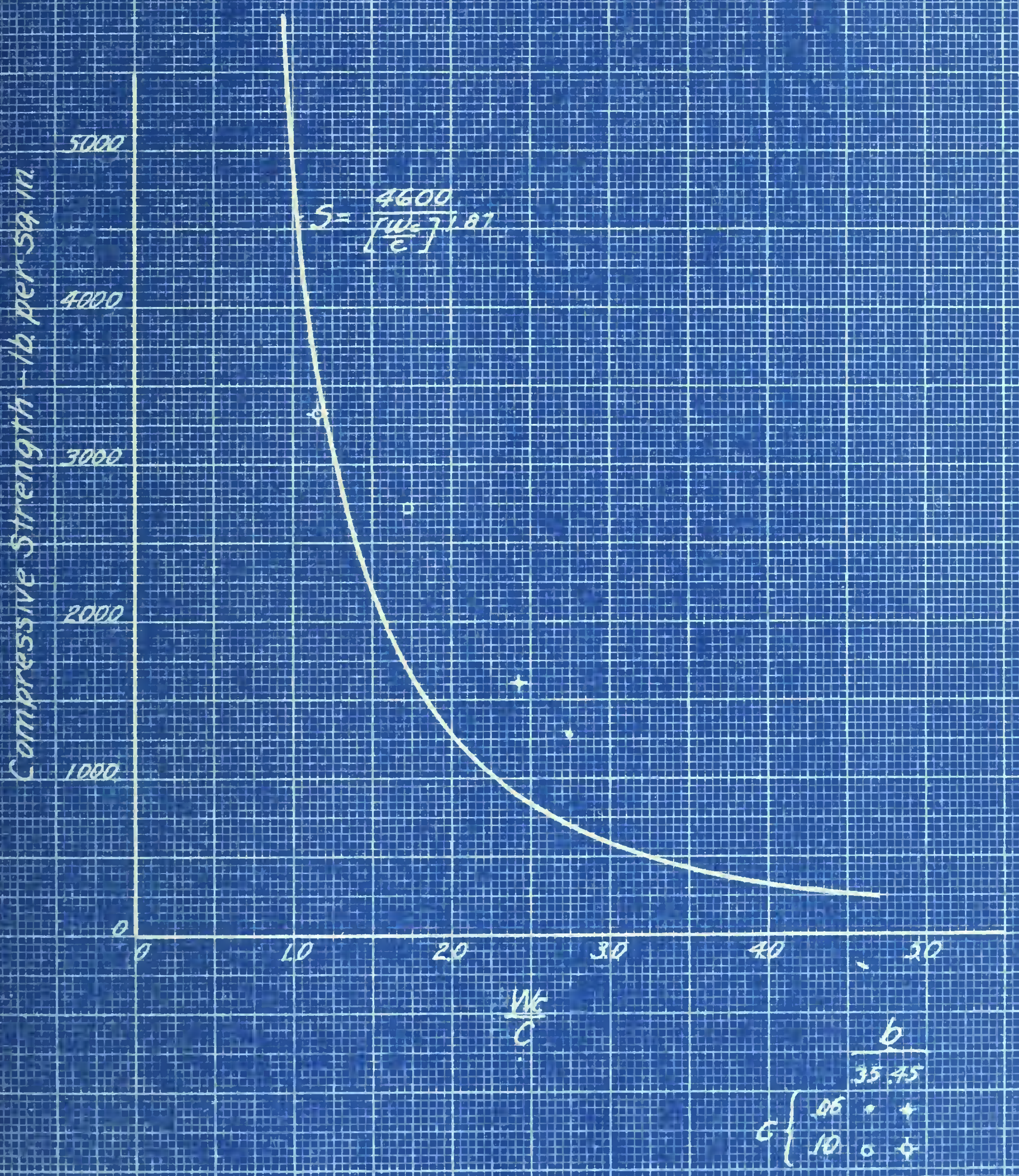
RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO



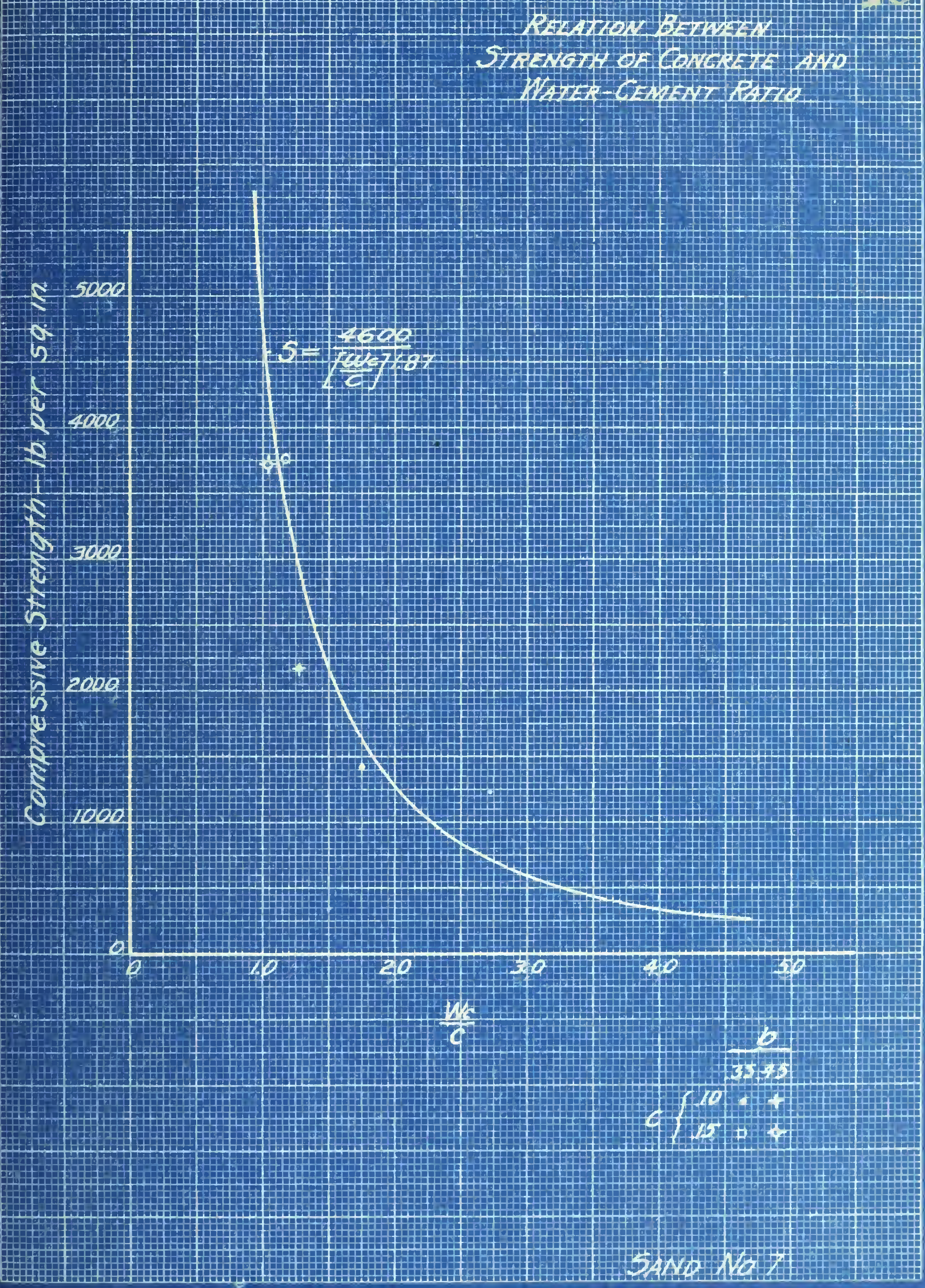
Relation between Strength of Concrete and Water-Cement Ratio

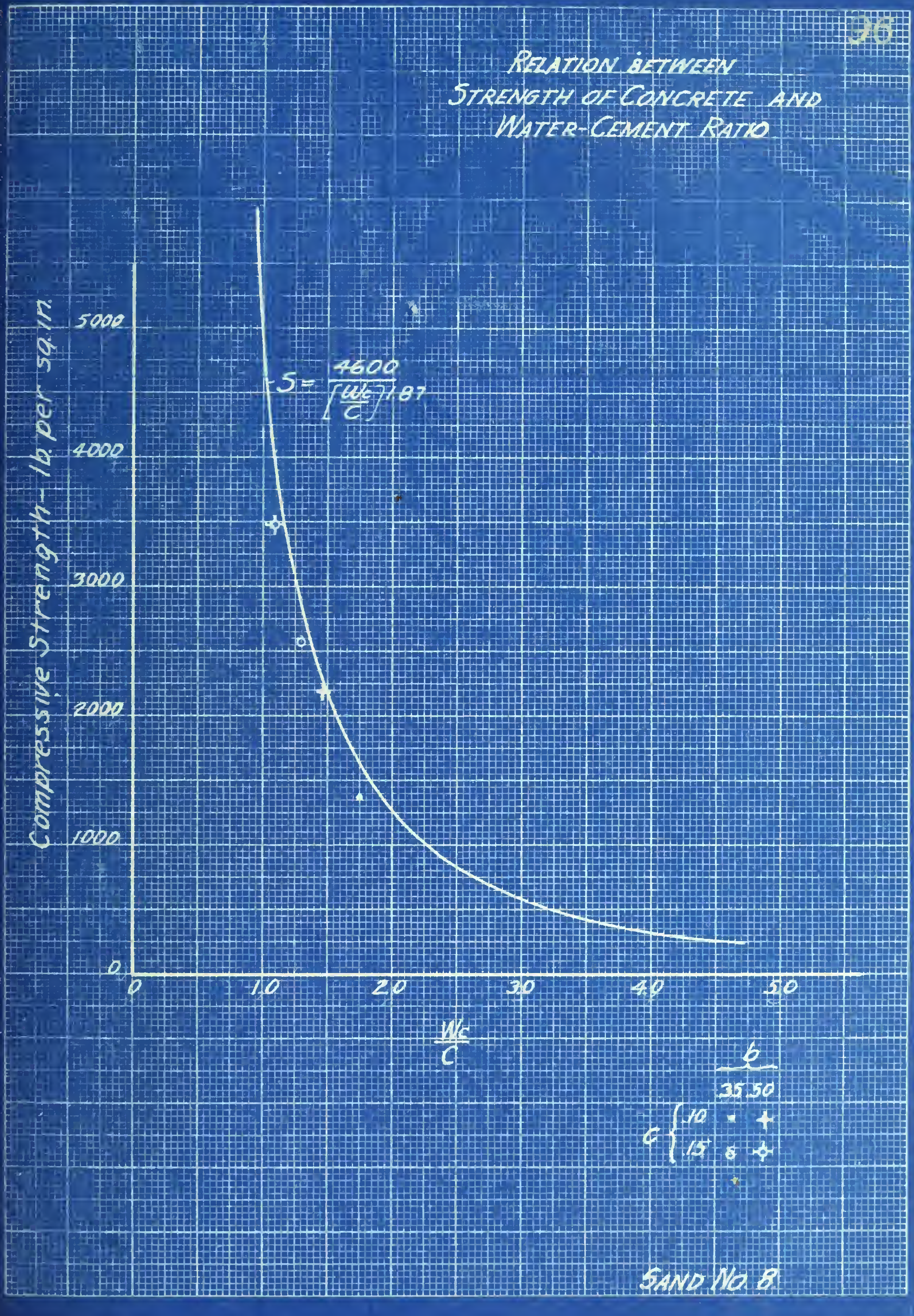


RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO

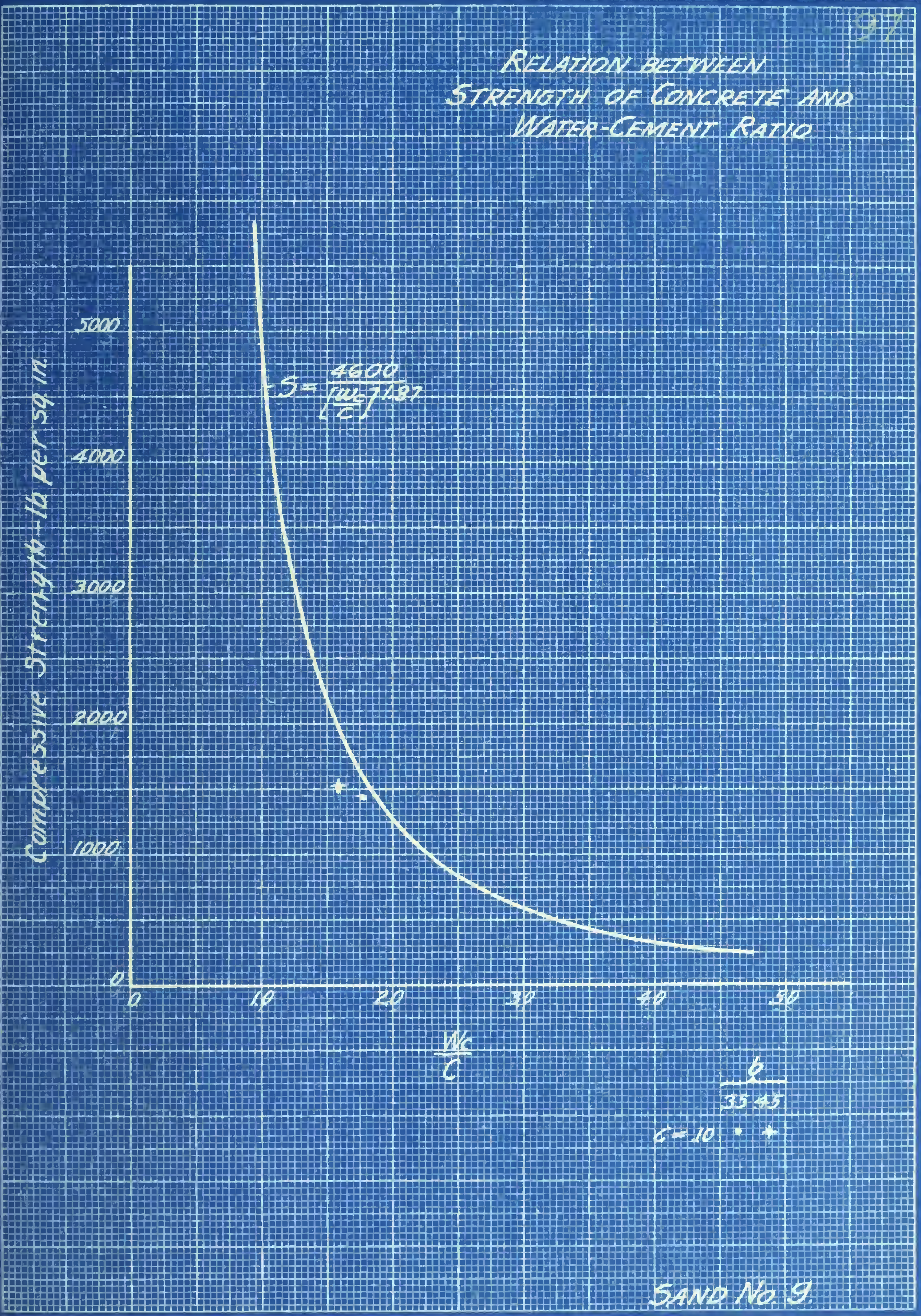


SAND NO. 6.


RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
Compressive Strength—lb. per sq. in.
5000
4000
3000
2000
1000
0
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
b
.35 .45
c .10
.15
SAND No 7

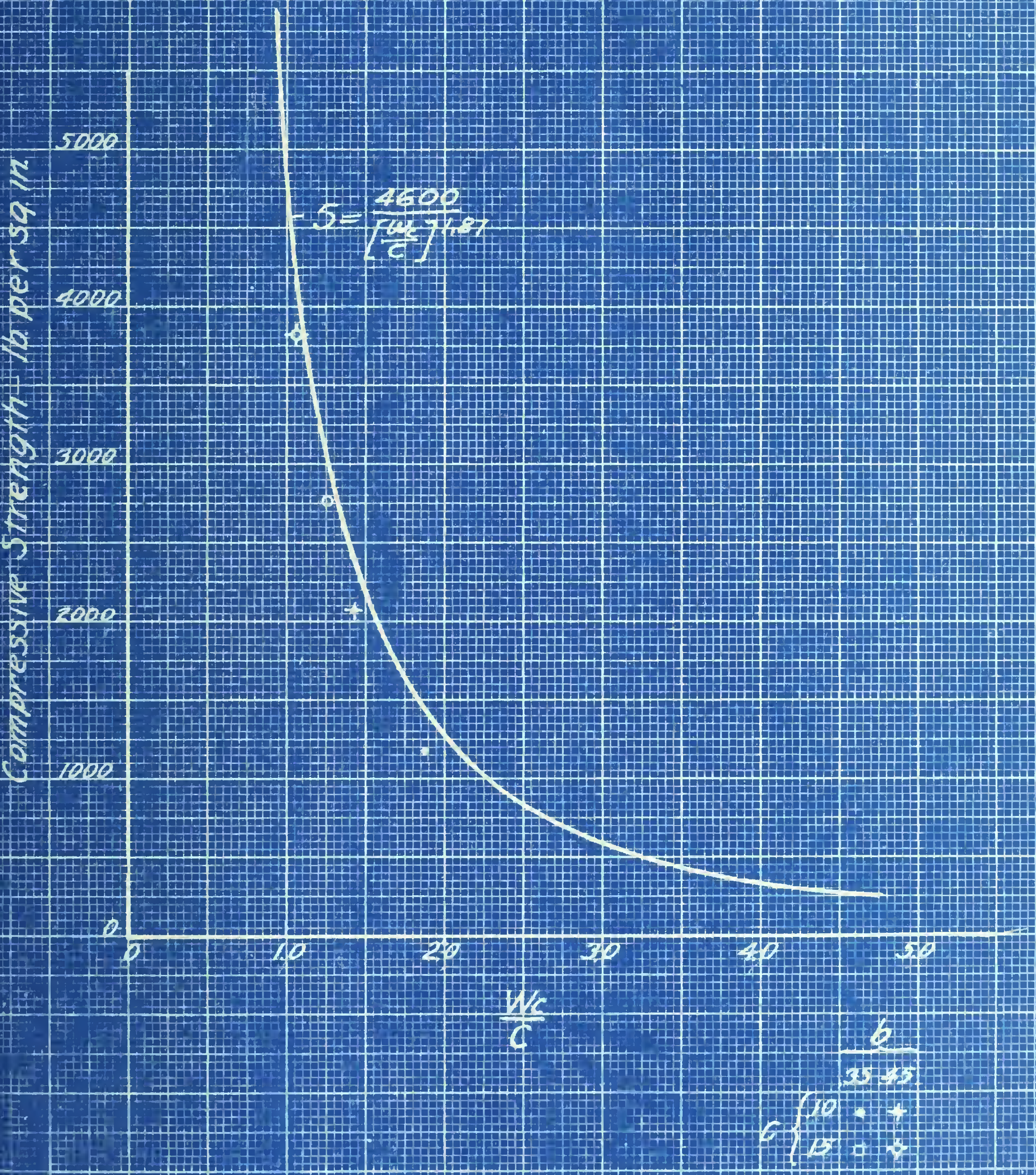


36
RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
b
35 50
C
10
15
SAND No. 8

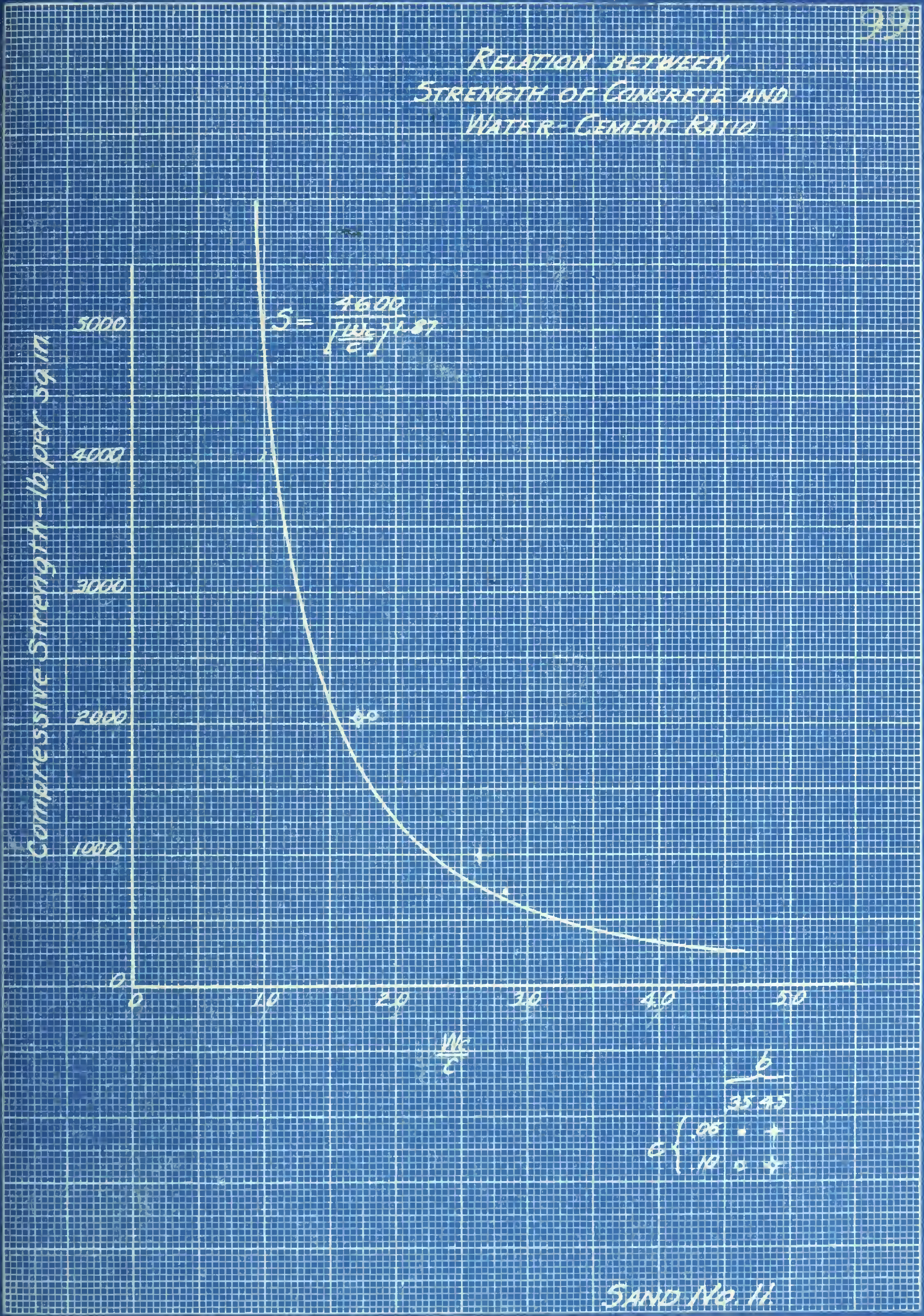


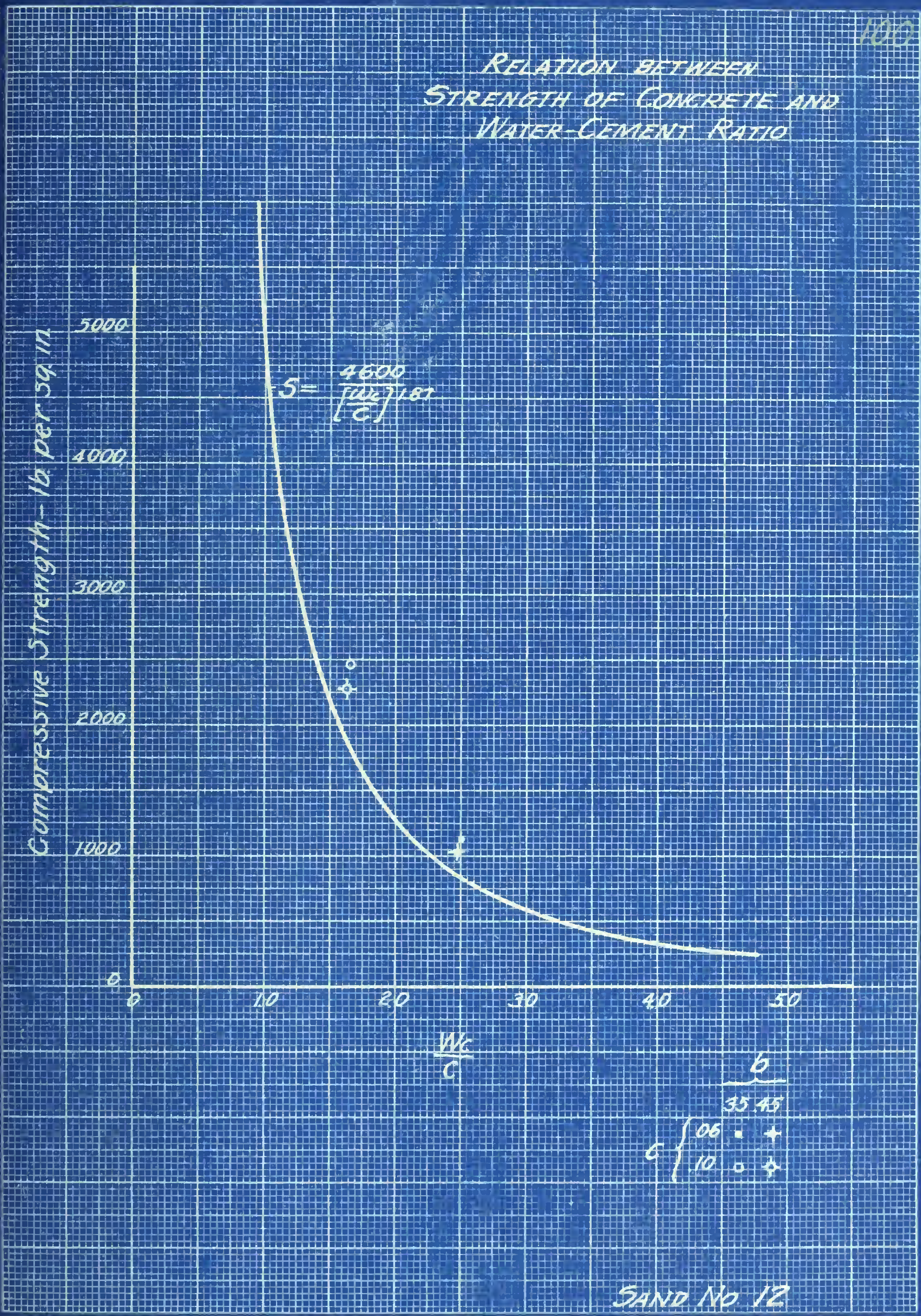
RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
Compressive Strength - lb per sq. in.
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
6
3.5 4.5
C = 1.0
SAND No. 9.

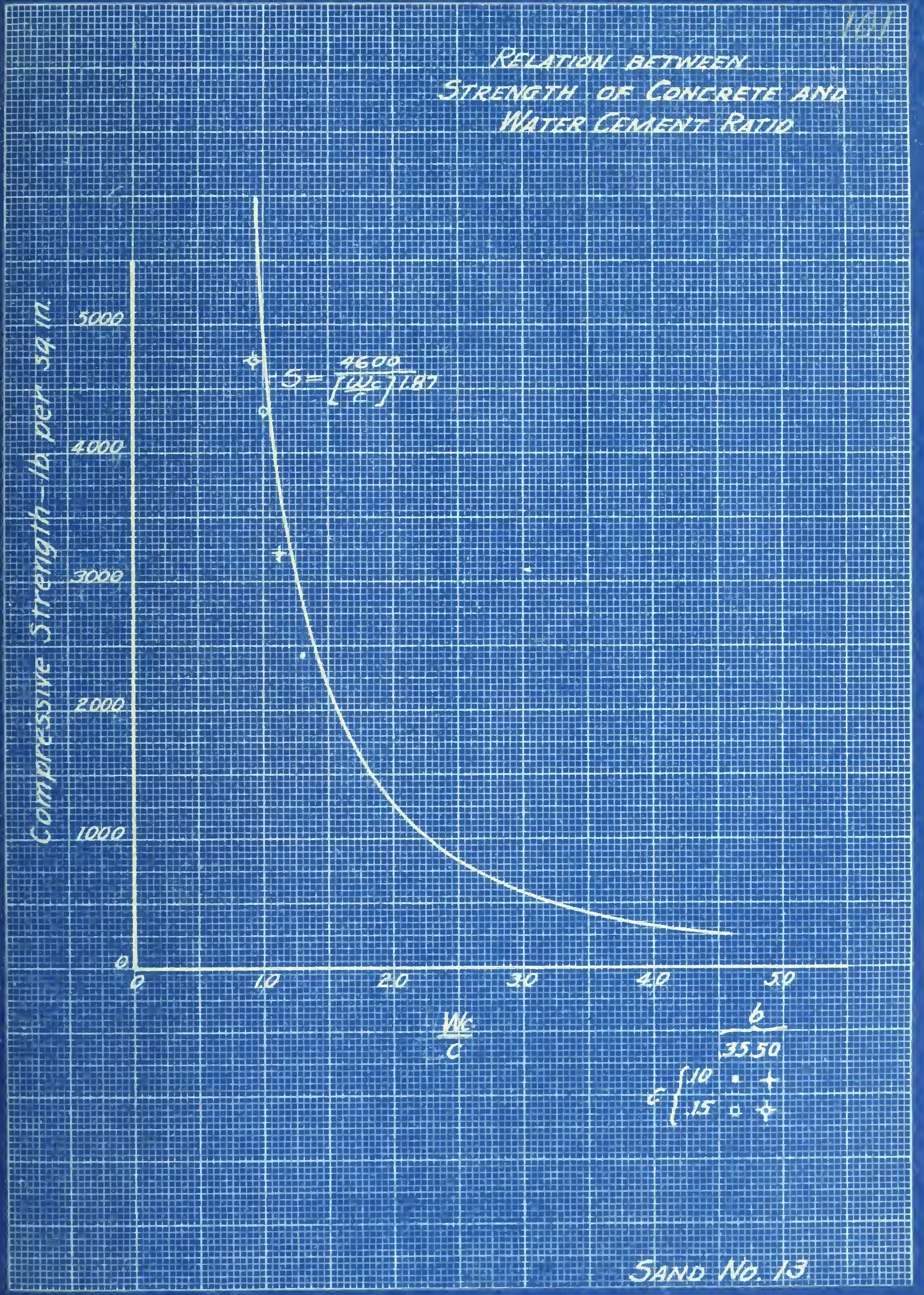
RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO

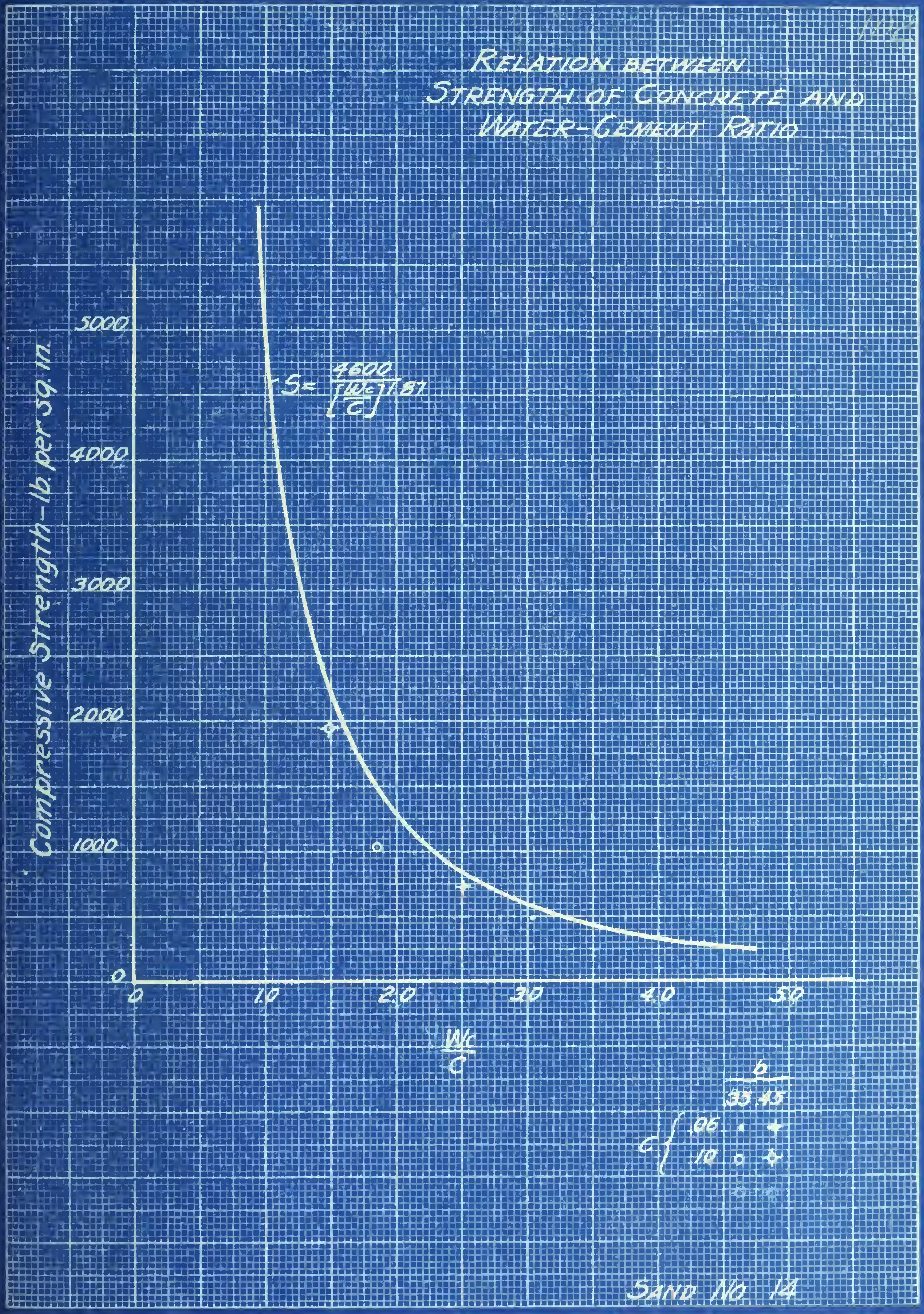


SAND No. 10

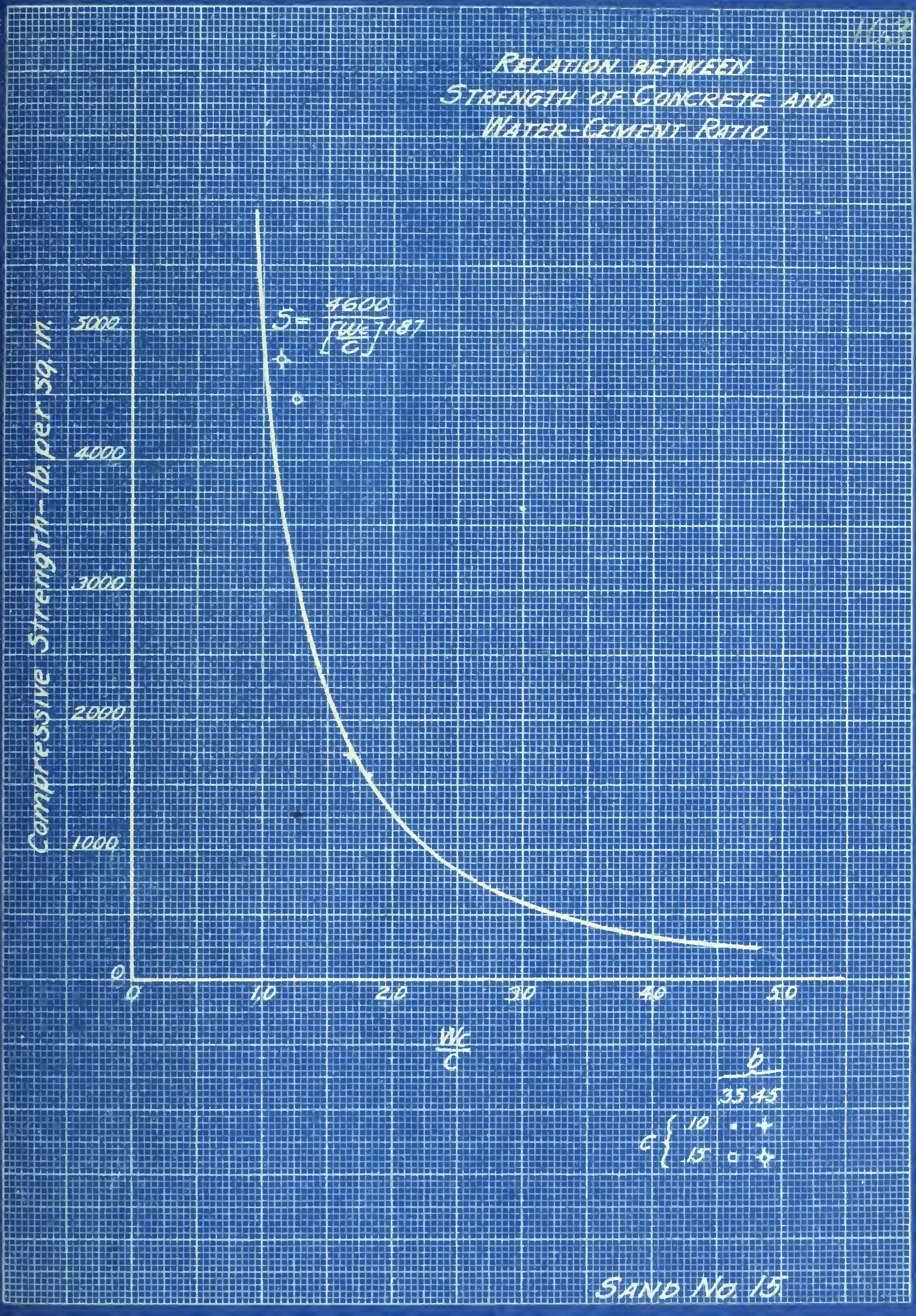

99
Relation between
Strength of Concrete and
Water-Cement Ratio
S = 4600 / [Wc/c] 1.87
5000
4000
3000
2000
1000
0
Compressive Strength - lb per sq in
0
1.0
2.0
3.0
4.0
5.0
Wc/c
b
35 45
.06
.10
c
Sand No. 11.


100
RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
S = 4600 / [Wc/C]^1.87
Compressive Strength - lb per sq in
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
Wc/C
b
35 45
c
06
10
SAND No 12

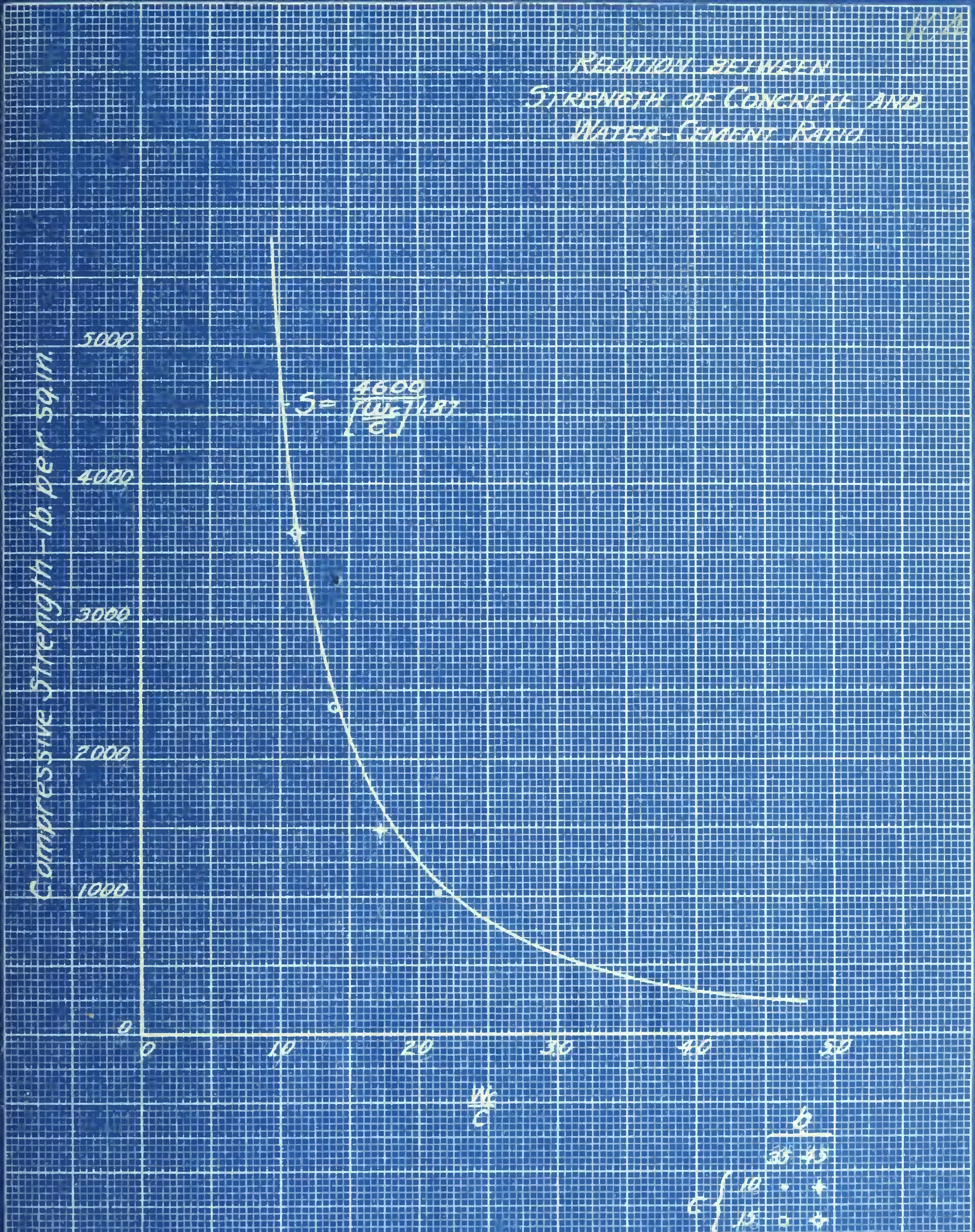

181
Relation between
Strength of Concrete and
Water Cement Ratio
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
Compressive Strength – lb per sq in.
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
b
35 50
c 10
.15
Sand No. 13



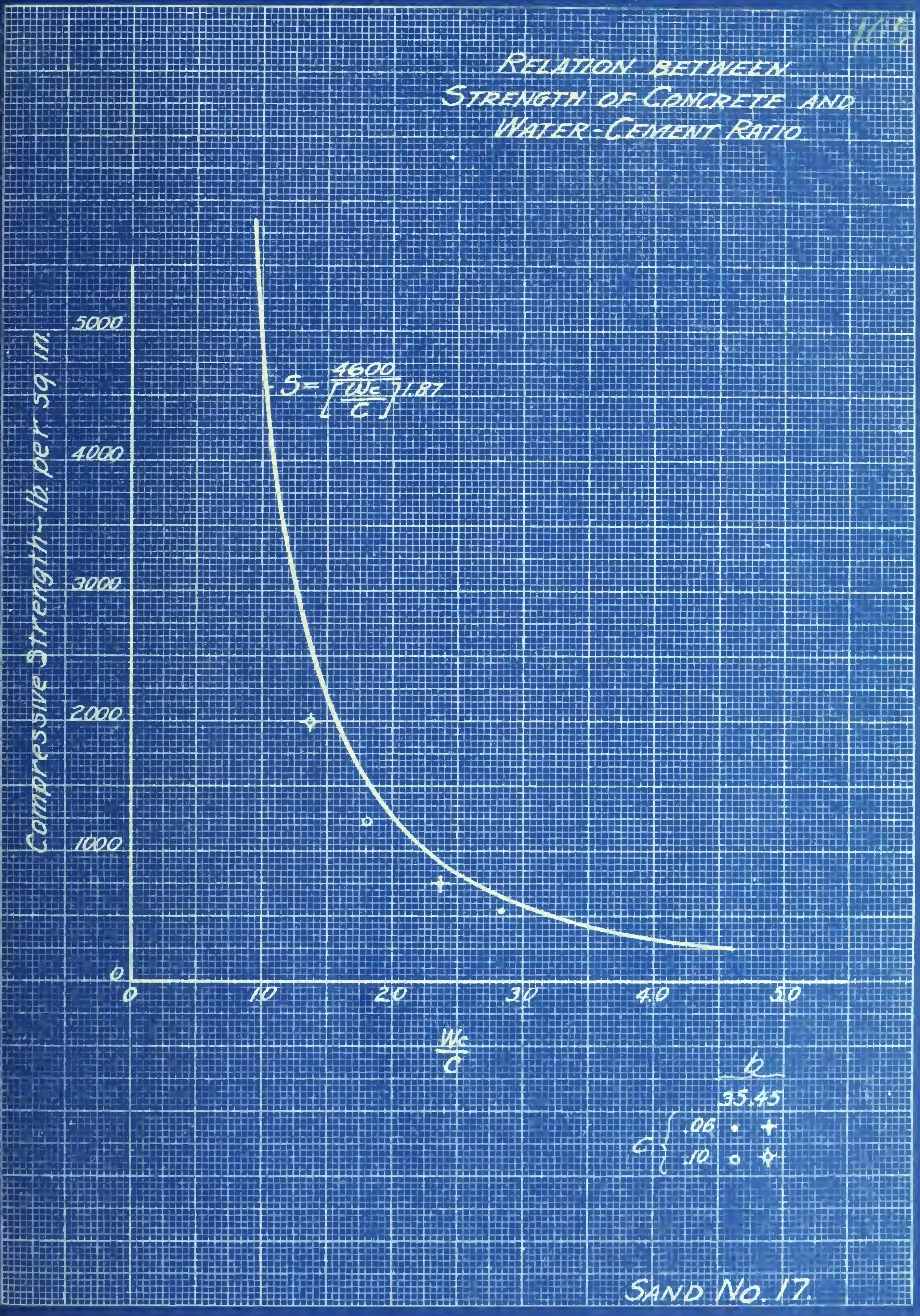
RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
Compressive Strength - lb. per sq. in.
$S = \dfrac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
b
.33 .45
c .06
.10
SAND No. 14



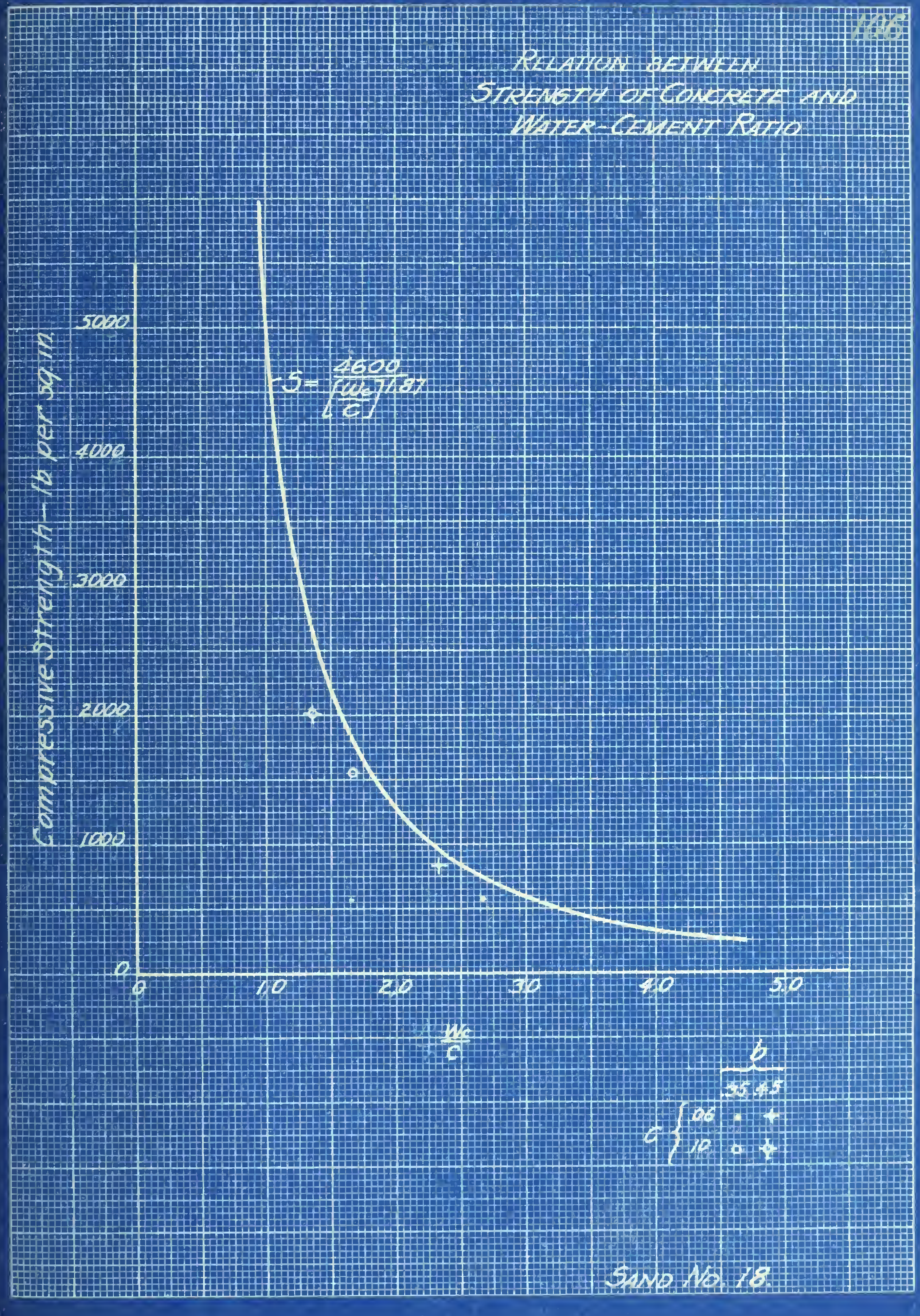
H-3
RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
b
35 45
10
15
c
SAND No. 15

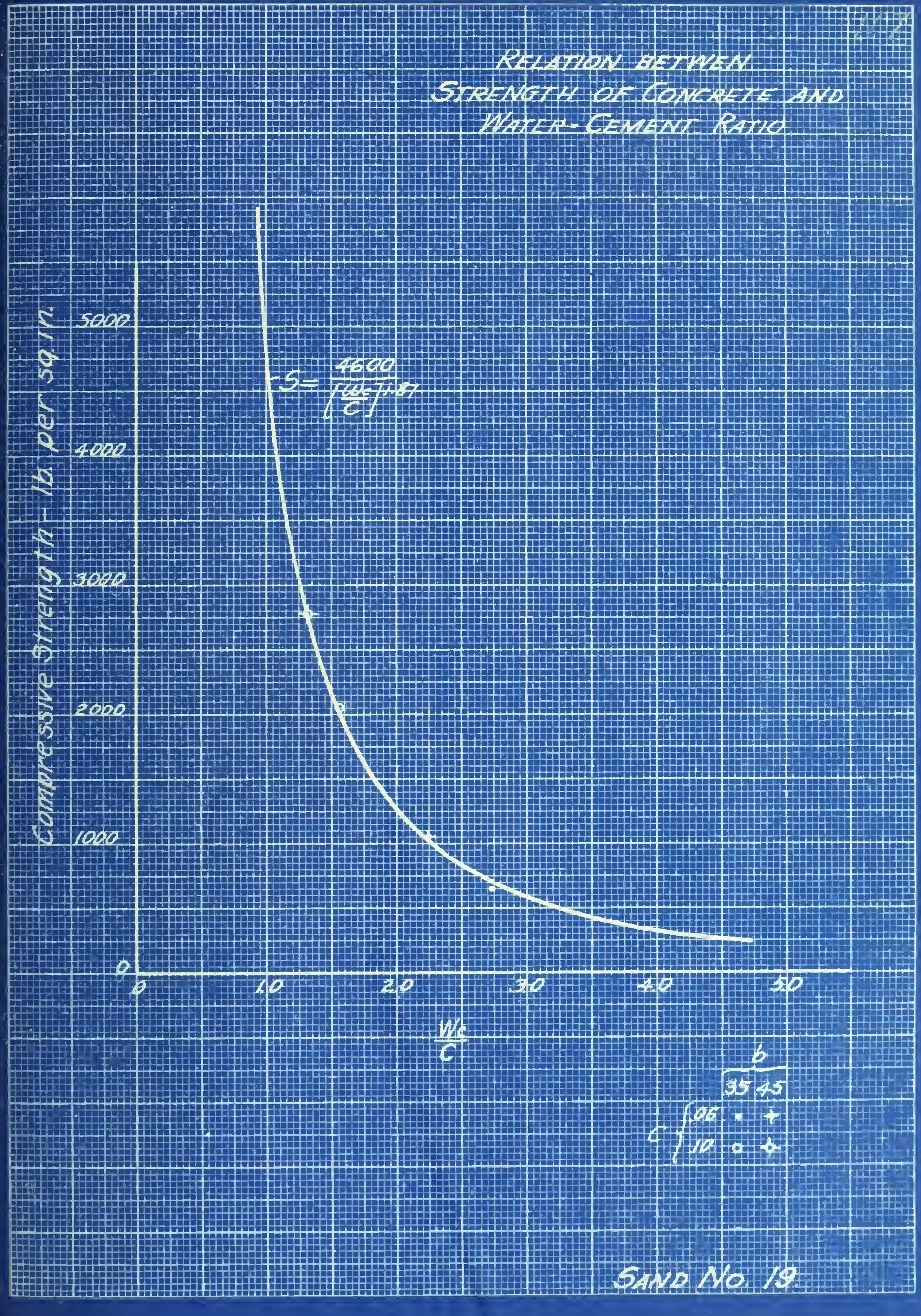


RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
$\frac{W_c}{C}$
b
35
45
C
10
15
SAND No 16

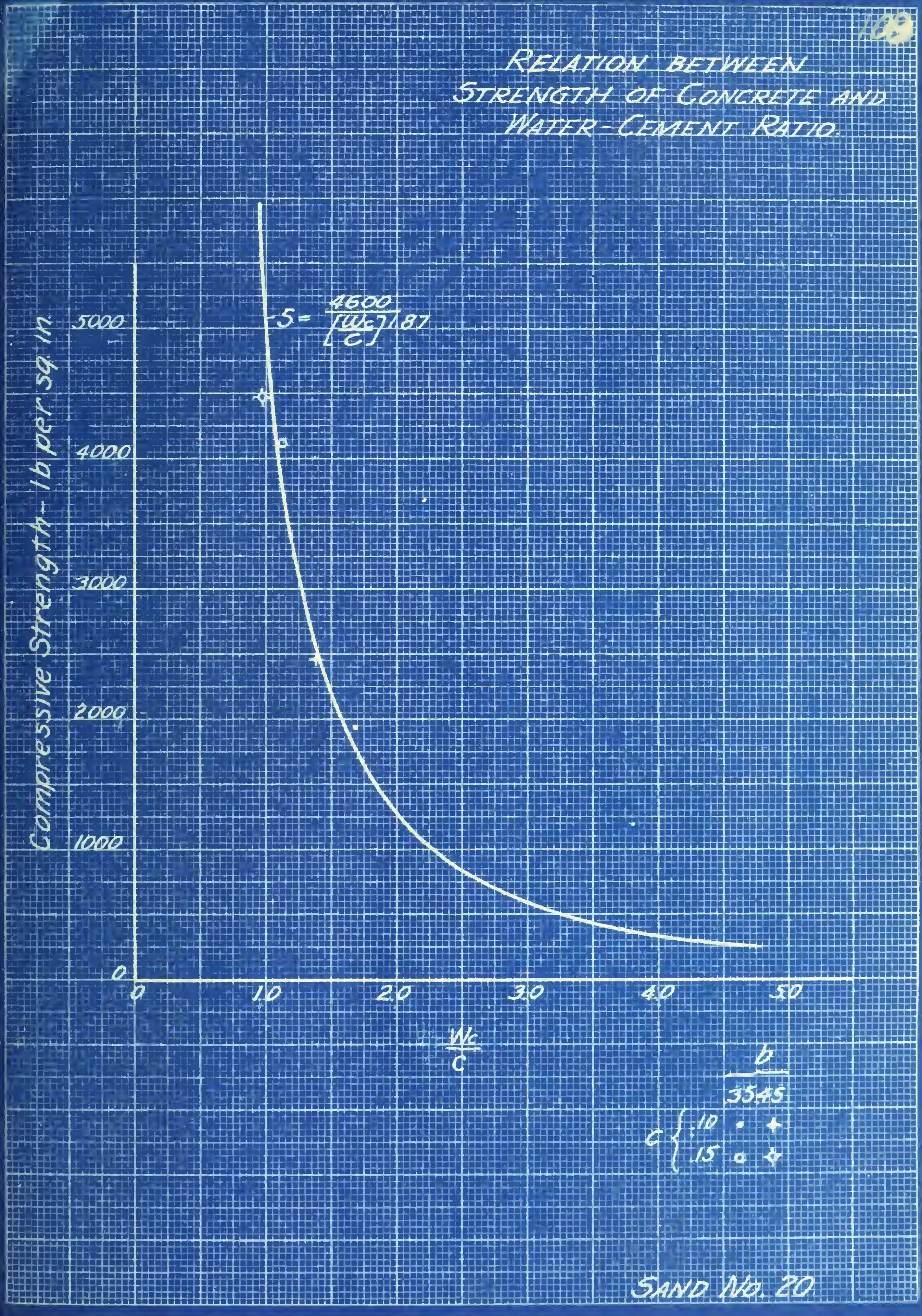


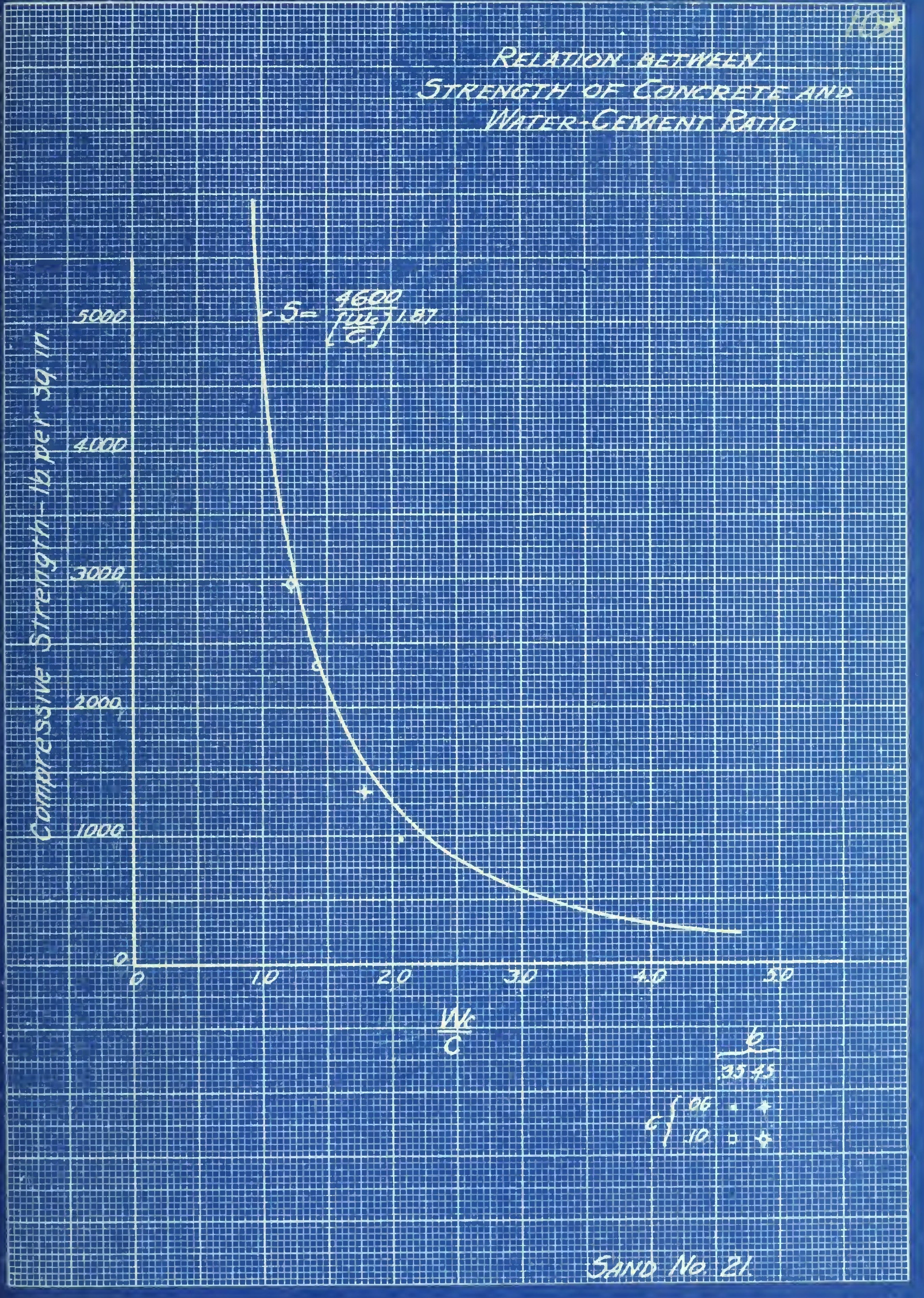
RELATION BETWEEN STRENGTH OF CONCRETE AND WATER-CEMENT RATIO.
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
Compressive Strength – lb. per sq. in.
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
b
35.45
c
.06
.10
SAND NO. 17.


RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
S = 4600 / [Wc/C]^1.87
Compressive Strength - lb per sq. in.
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
Wc/C
b
35 45
C 06
10
SAND NO. 18.



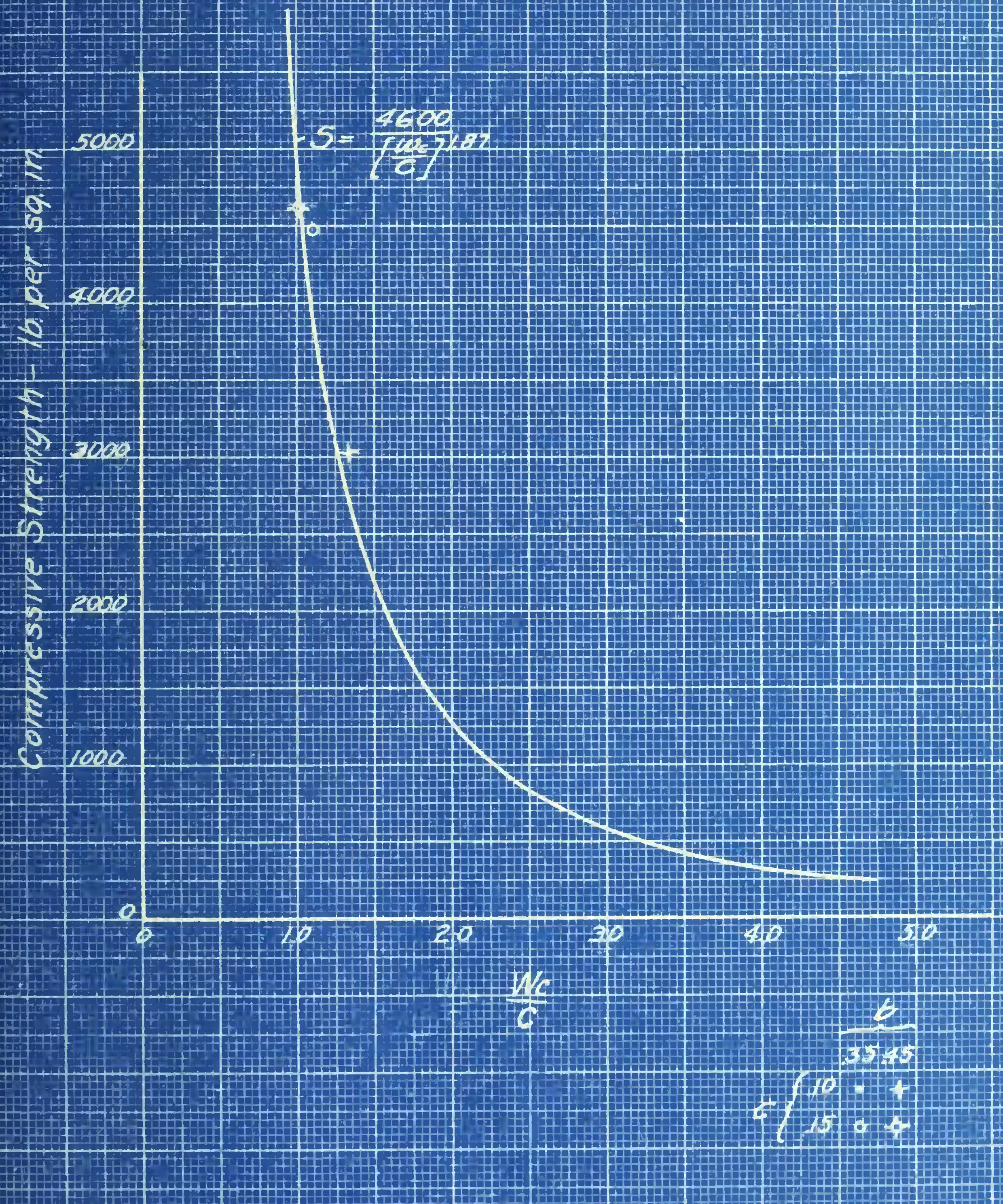
17
RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
b
35 45
C .06
.10
SAND NO. 19


RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO.
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
Compressive Strength - lb per sq. in.
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
b
35 45
C
.10
.15
SAND NO. 20

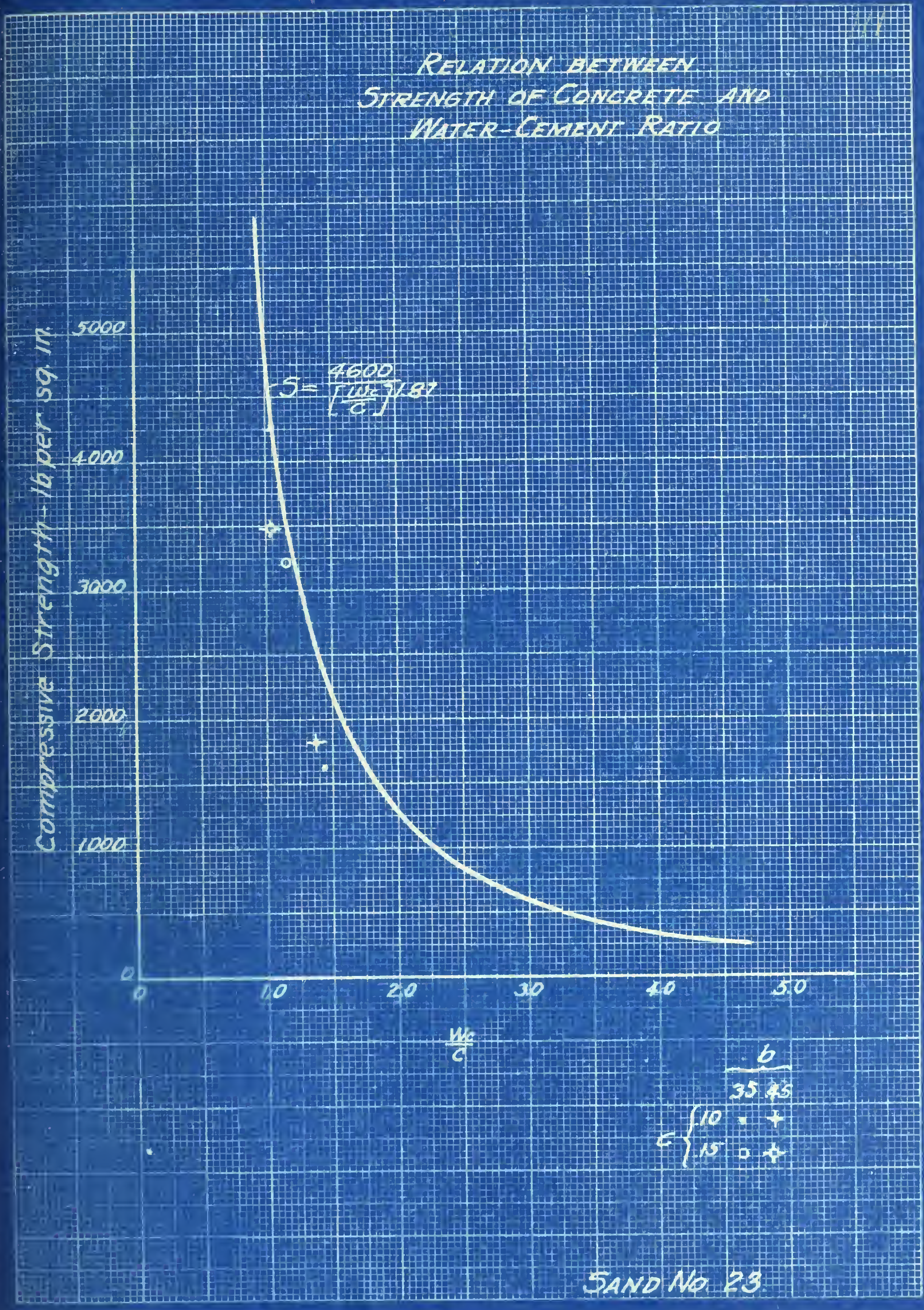


RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
Compressive Strength - lb per sq in.
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
b
.35 .45
c .06
.10
SAND No. 21

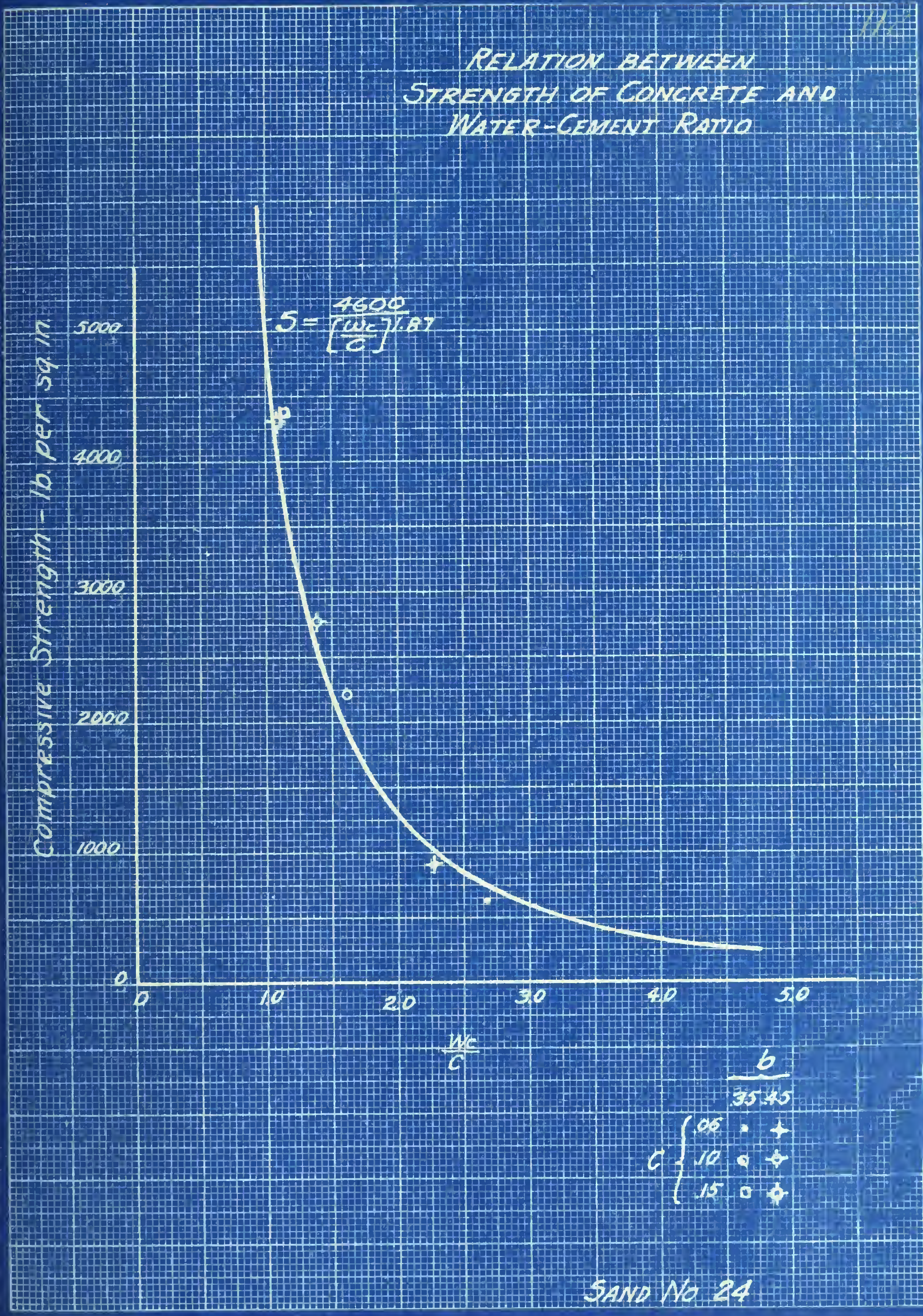
RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER CEMENT RATIO



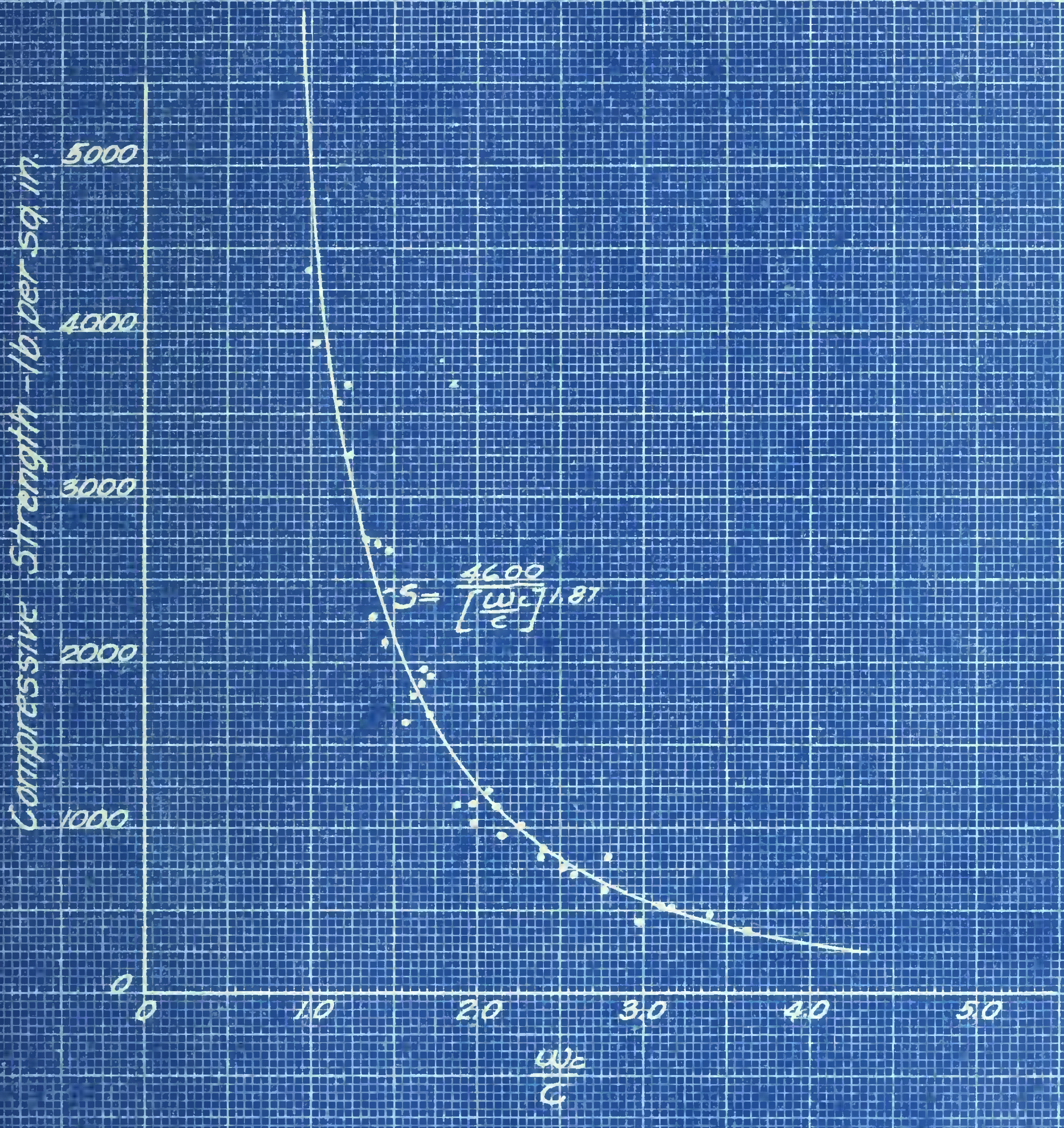
SAND NO. 22



RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
$S = \frac{4600}{\left[\frac{Wc}{c}\right]^{1.87}}$
Compressive Strength - lb per sq. in.
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
$\frac{Wc}{c}$
b
35 .45
c .10
.15
SAND No. 23

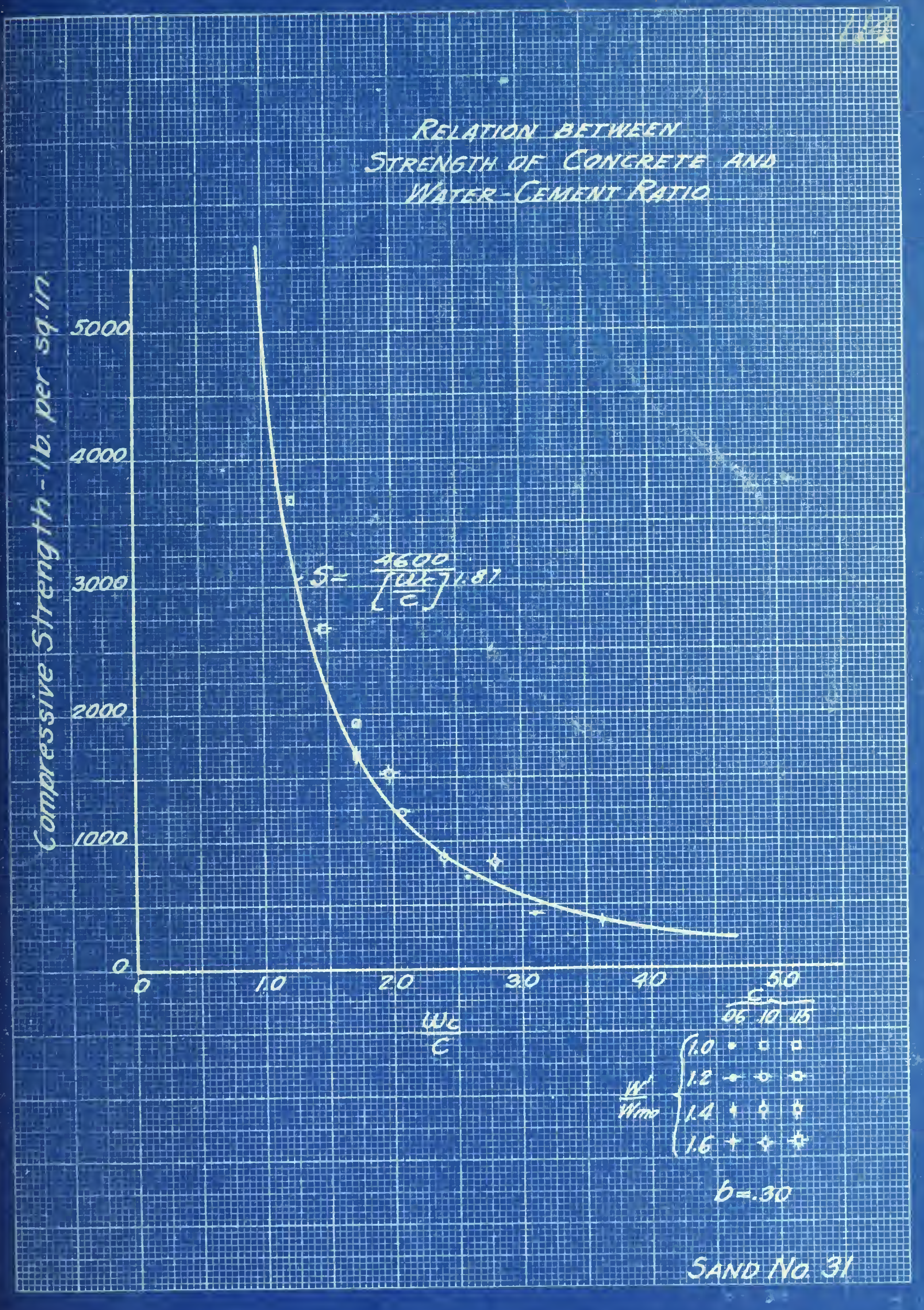


RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
S = 4600 / [Wc/C]^1.87
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
Wc/C
b
35 45
C
.06
.10
.15
SAND No. 24

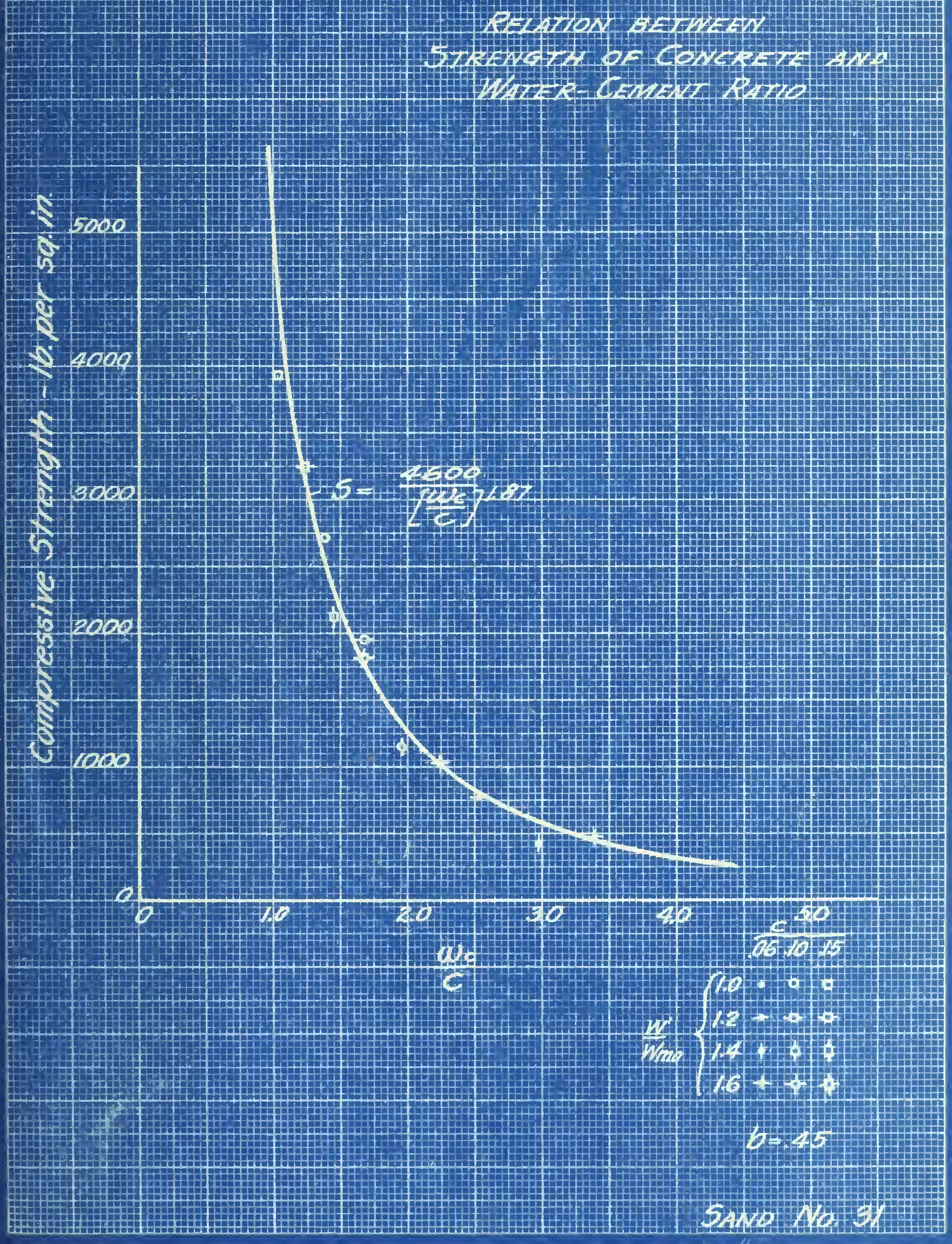


RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO

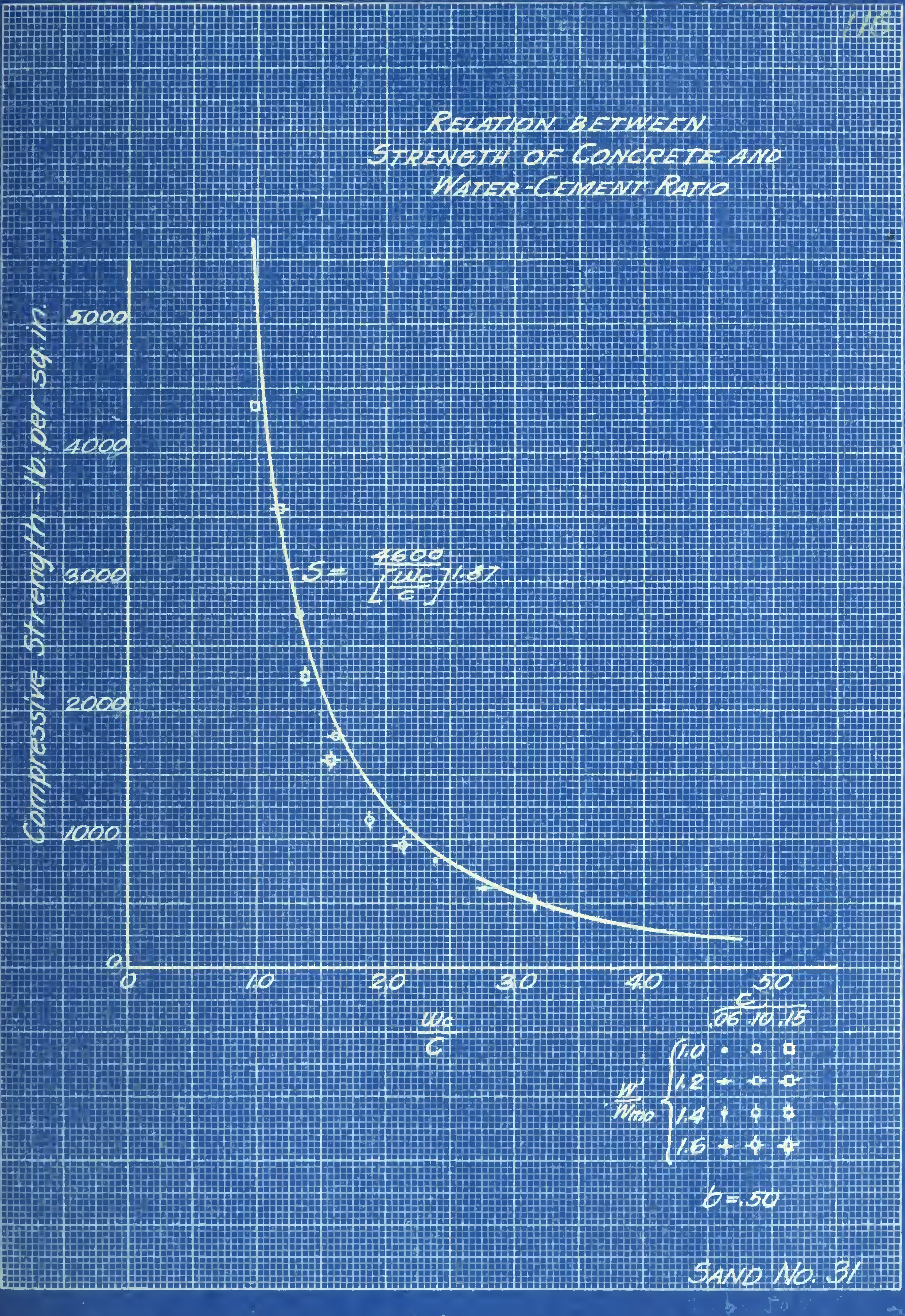
SAND NO. 31



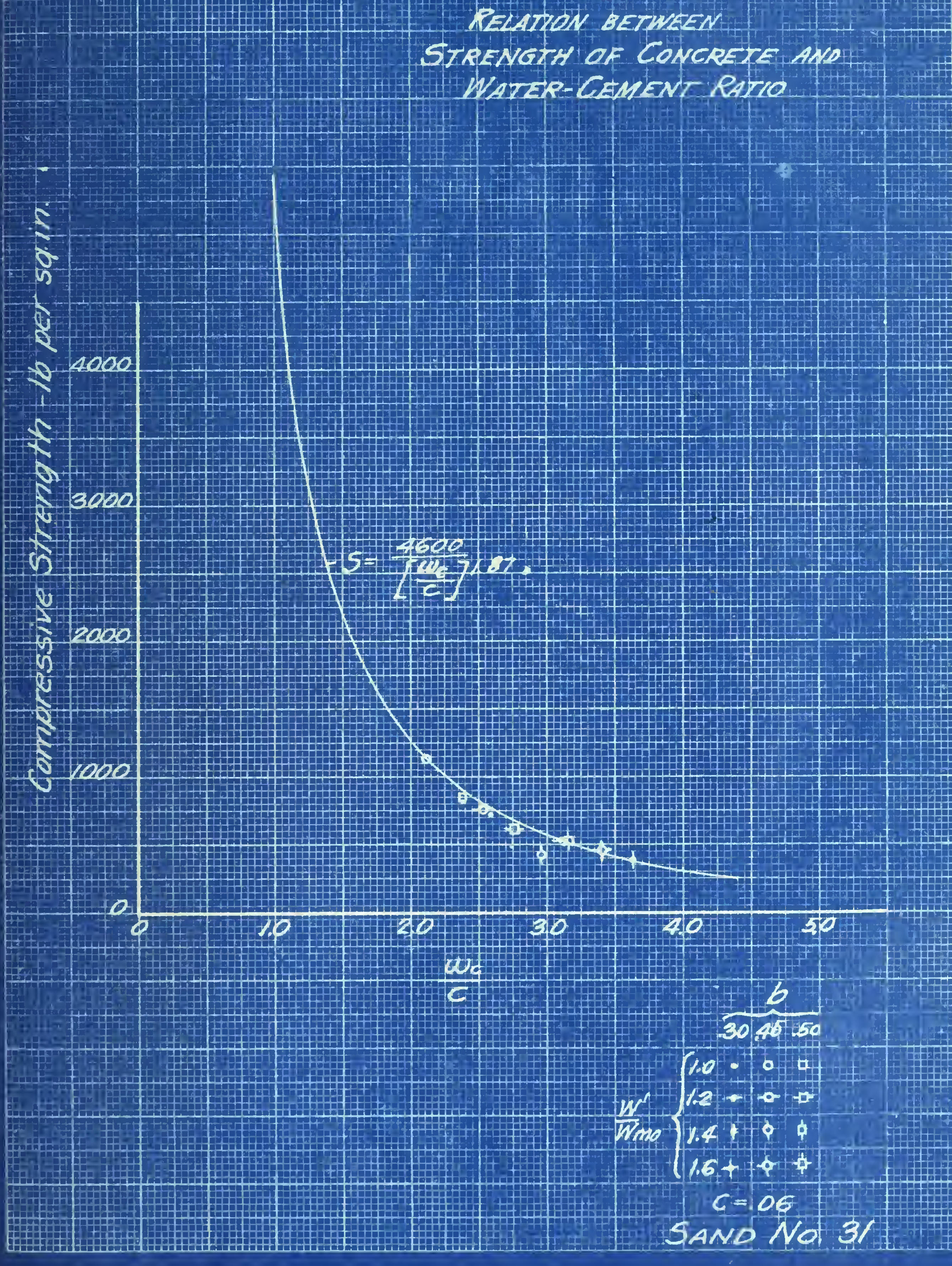
RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
$\frac{W_c}{C}$
C
.06 .10 .15
$\frac{W}{W_{mo}}$
1.0
1.2
1.4
1.6
b = .30
SAND No. 31

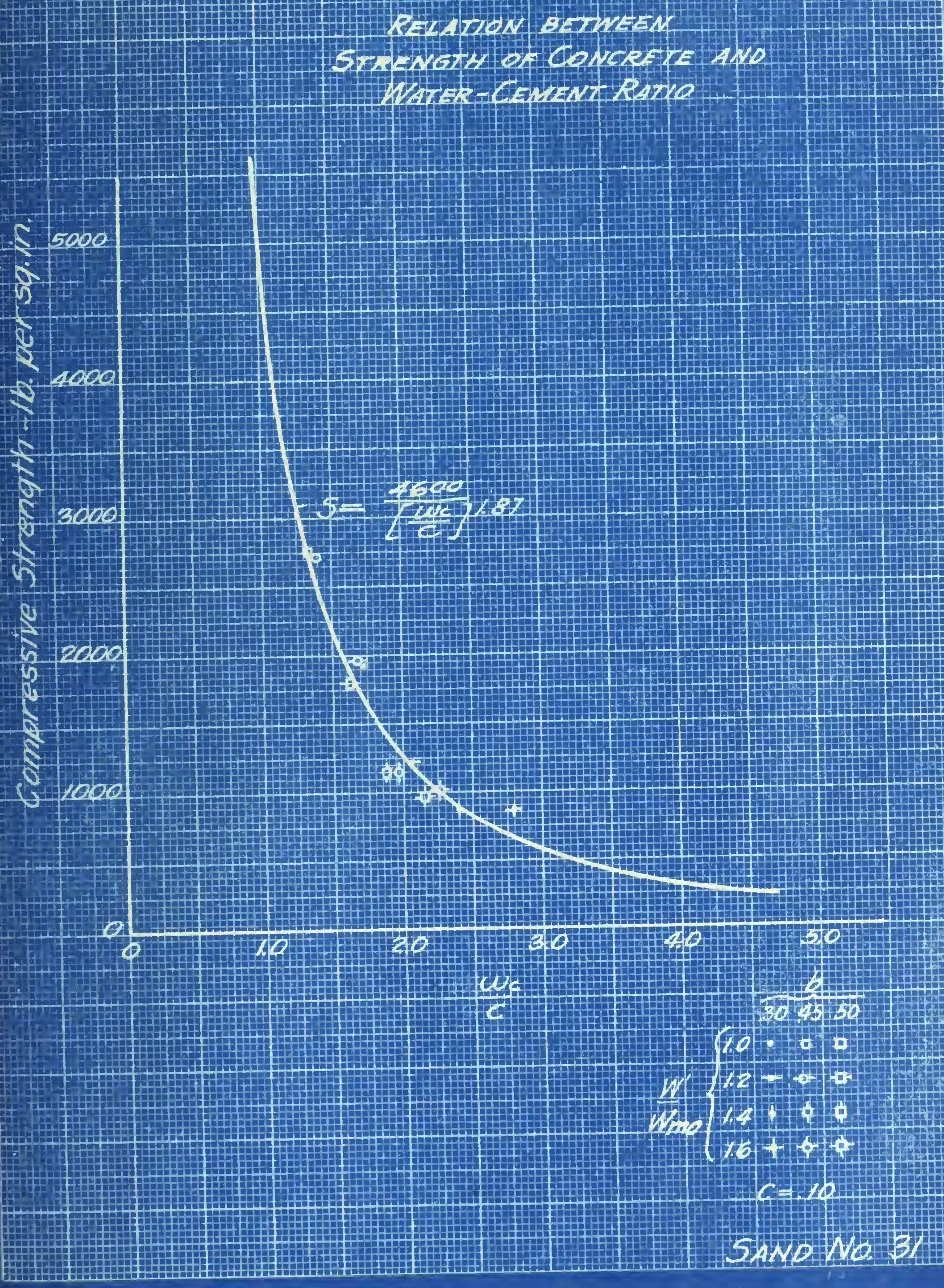


RELATION BETWEEN STRENGTH OF CONCRETE AND WATER-CEMENT RATIO

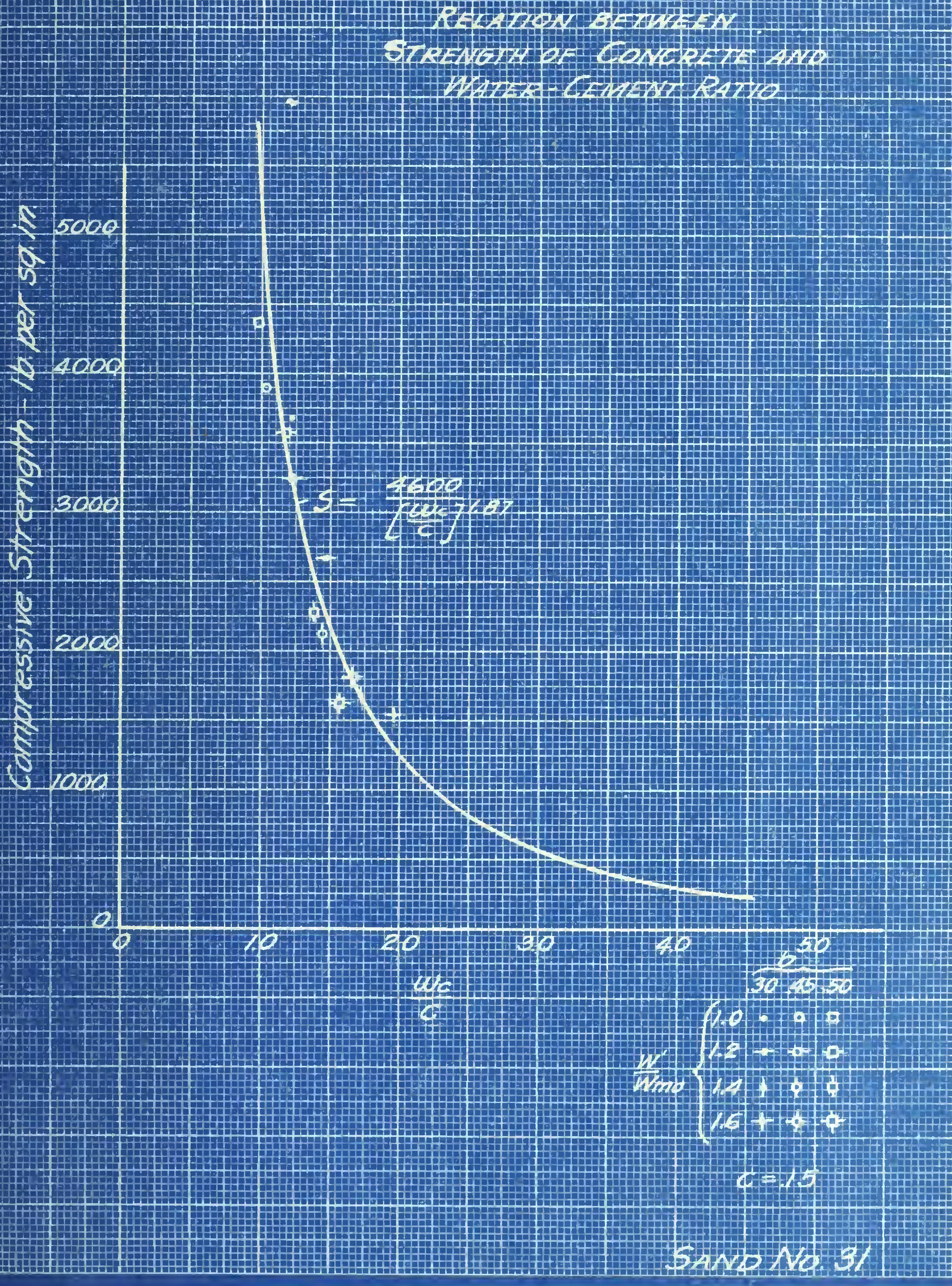


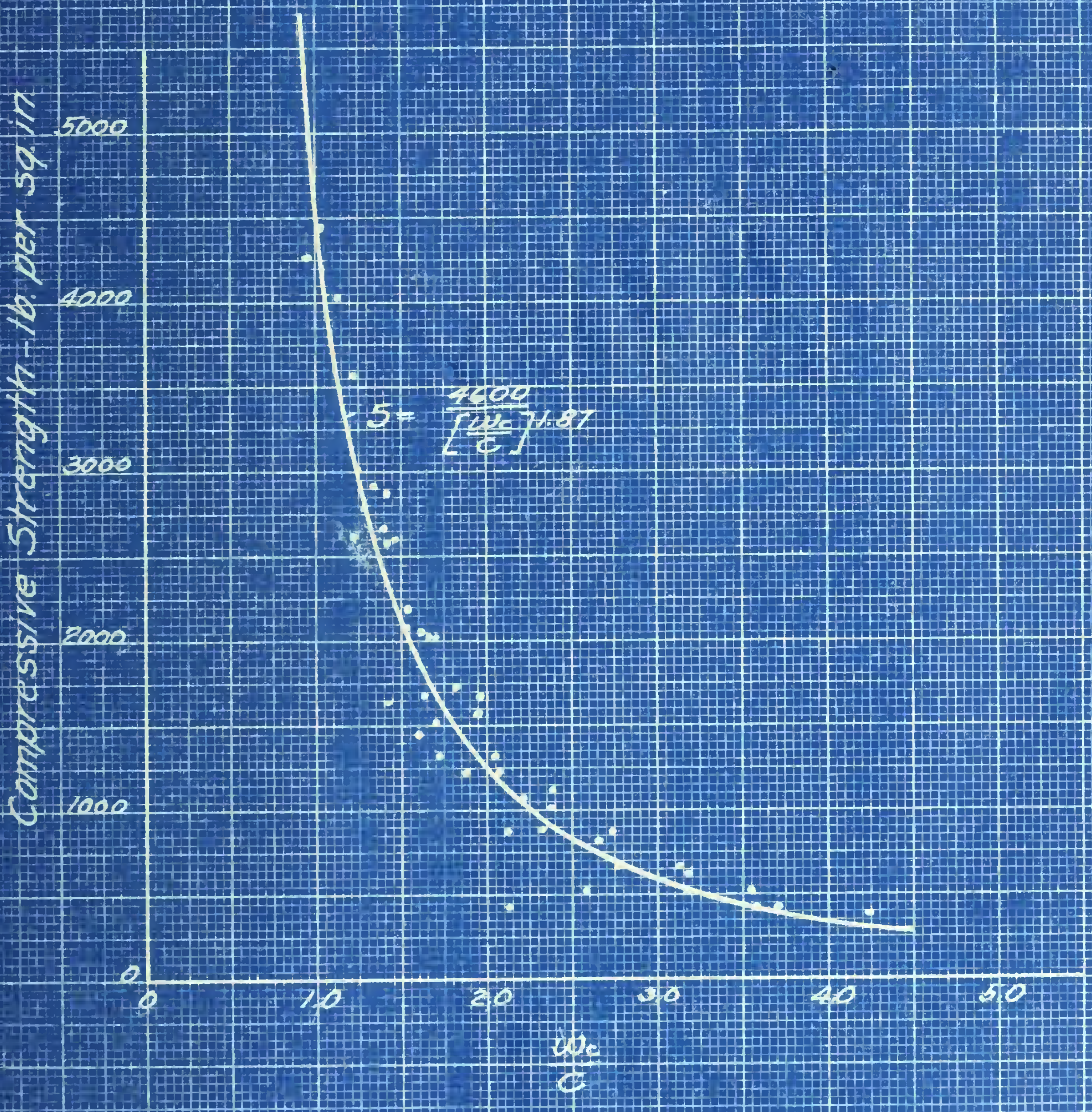
RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
$\frac{C}{}$
.06 .10 .15
$\frac{W'}{W_{mo}}$
1.0
1.2
1.4
1.6
b=.50
SAND NO. 31


RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
Compressive Strength - lb per sq. in.
4000
3000
2000
1000
0
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
b
.30 .40 .50
1.0
1.2
1.4
1.6
$\frac{W'}{W_{mo}}$
C = .06
SAND No. 31



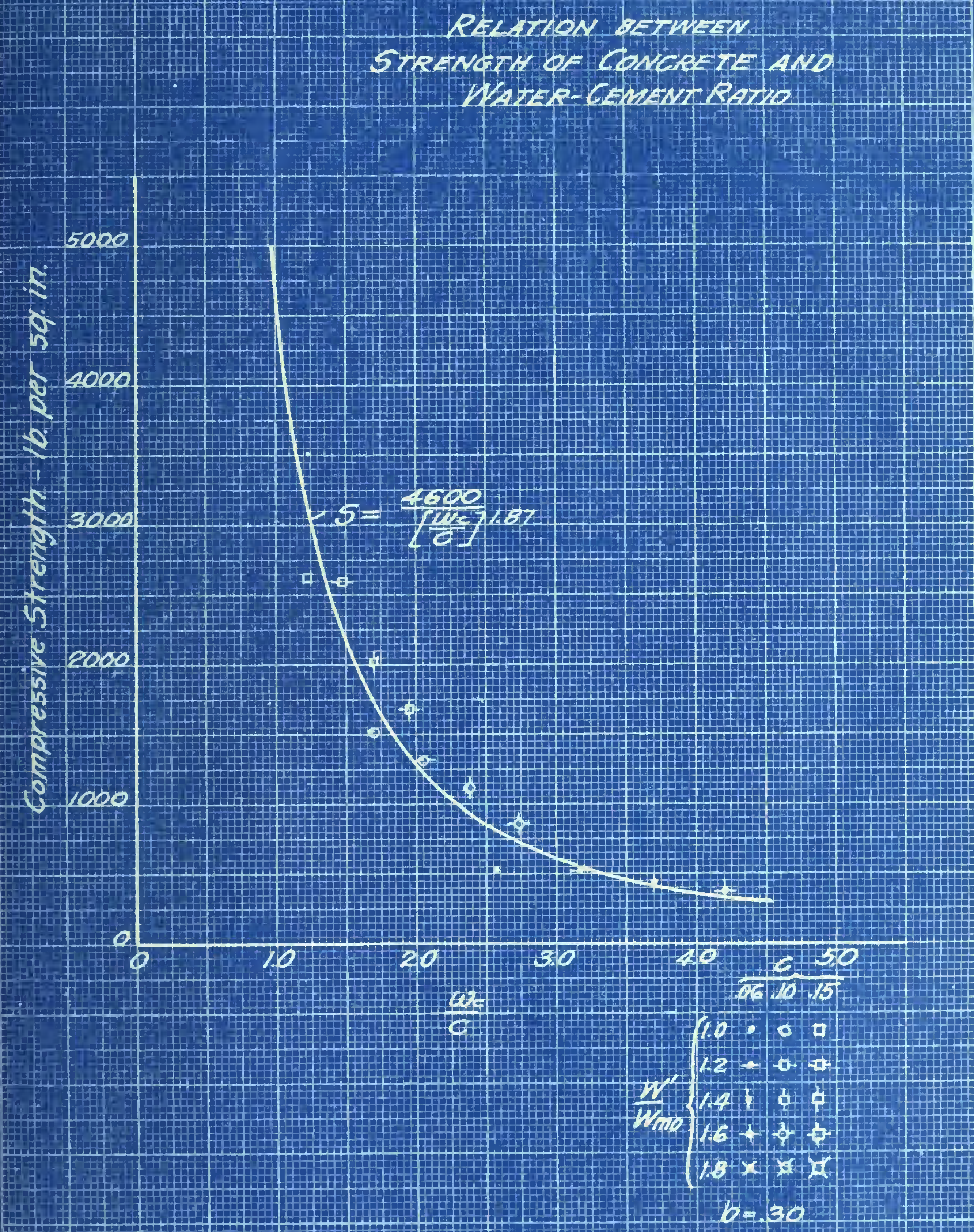
RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
b
.30 .45 .50
W'
Wmo
1.0
1.2
1.4
1.6
C = 1.0
SAND NO. 31


Relation between
Strength of Concrete and
Water-Cement Ratio
Compressive Strength - lb per sq. in.
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
Wc/C
S = 4600/[Wc/C]^1.87
b
30 .45 .50
W/Wmo
1.0
1.2
1.4
1.6
c = 1.5
Sand No. 31

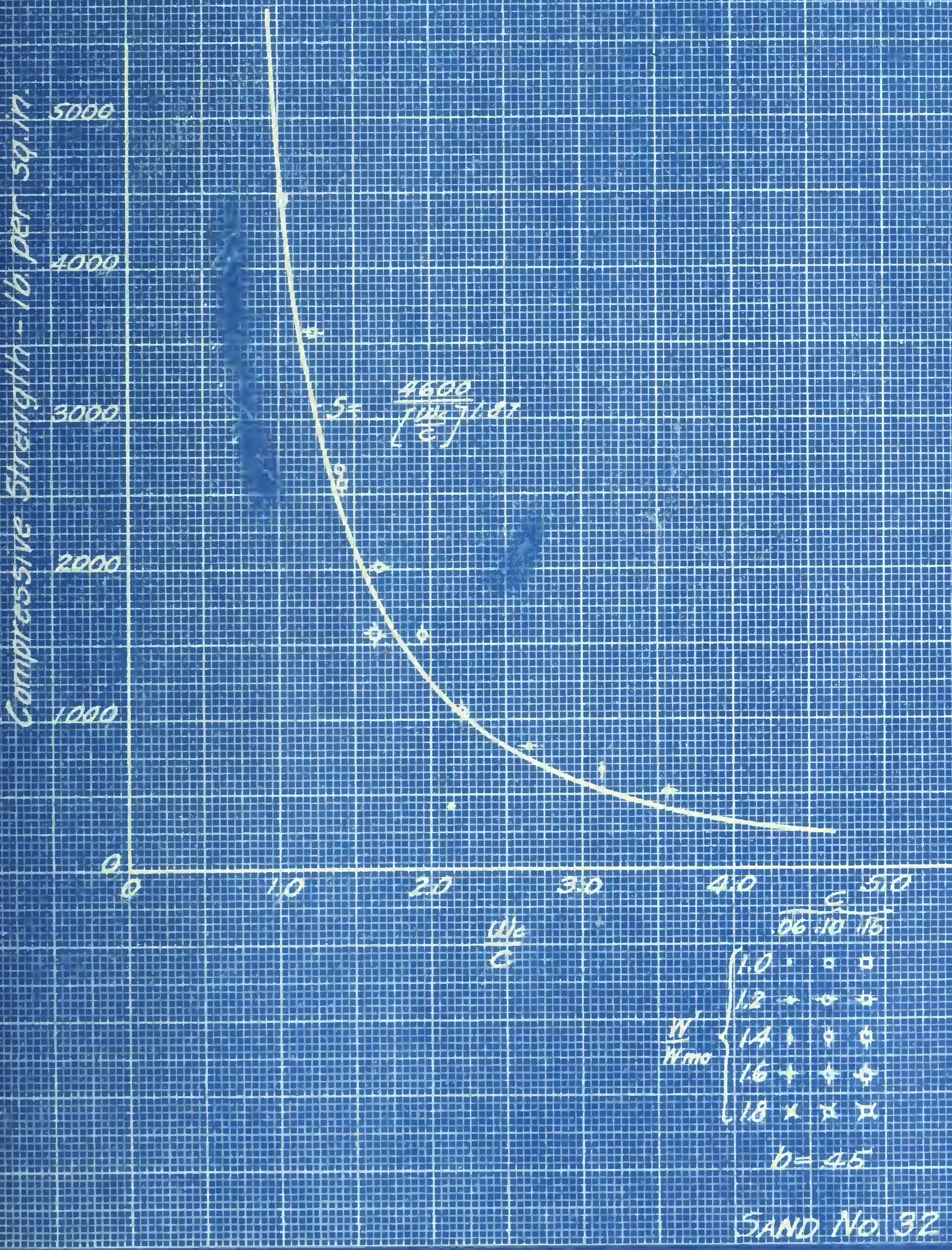


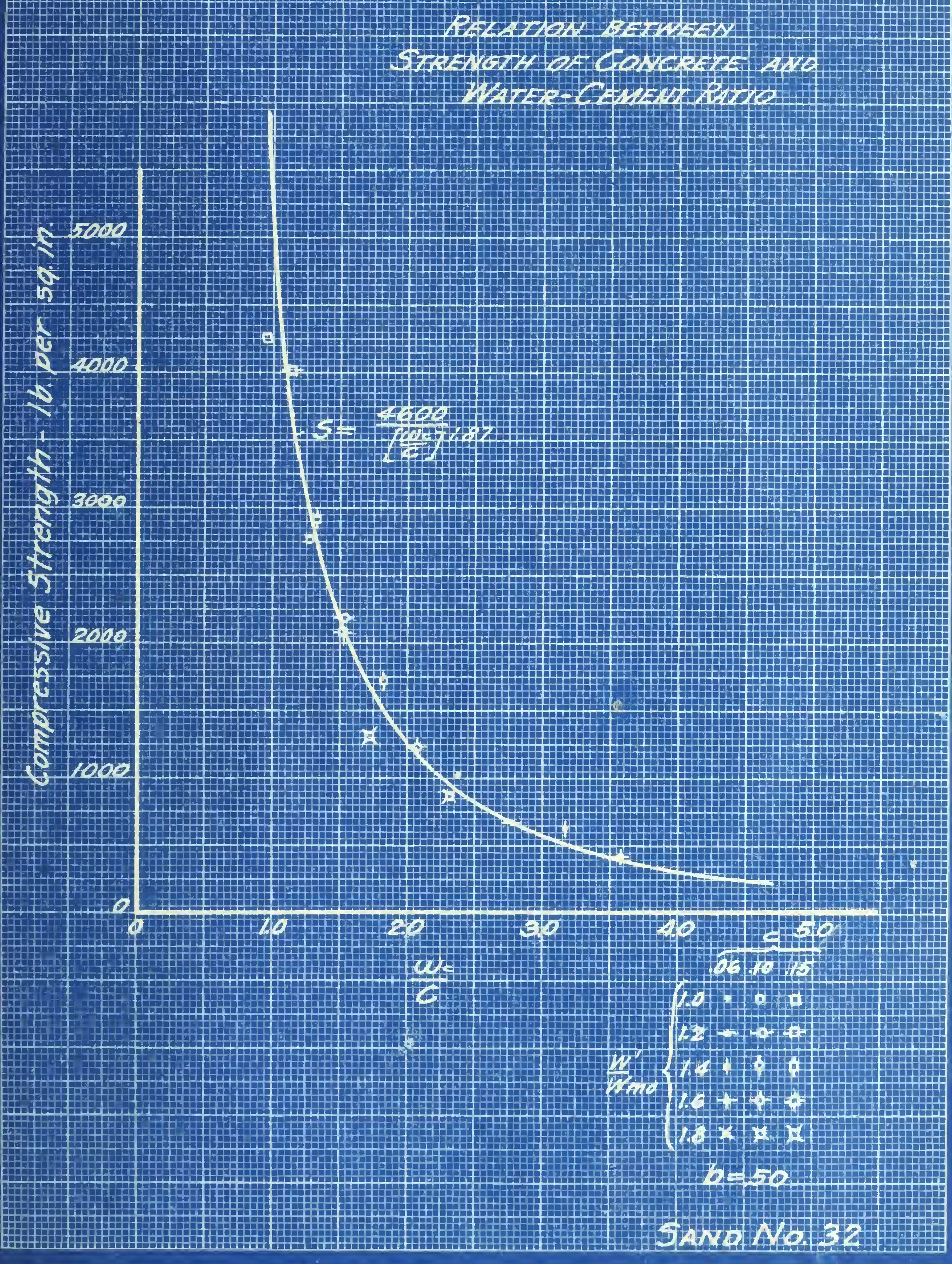
RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO

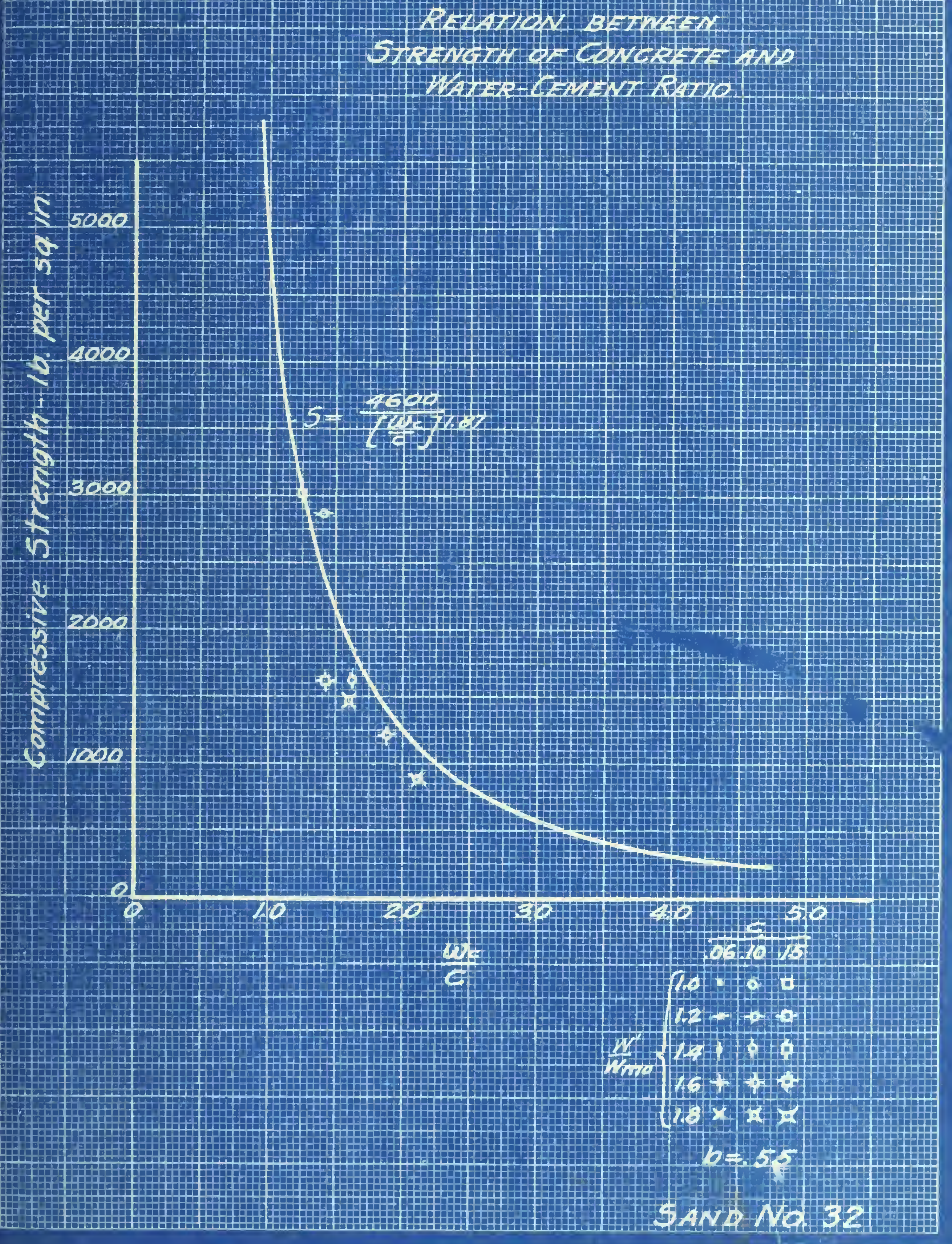
SAND No 32

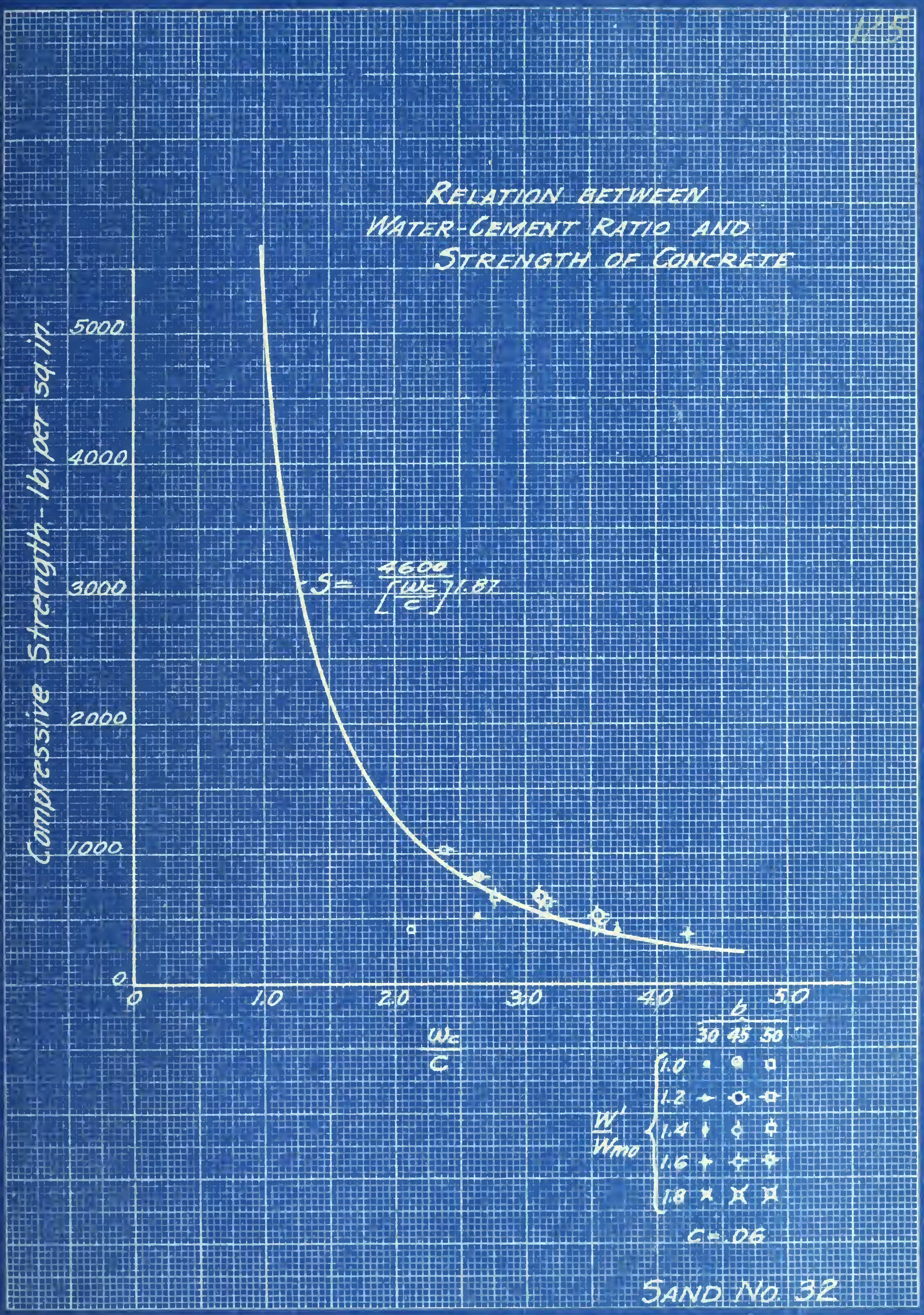

RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
c
.06 .10 .15
$\frac{W'}{W_{mo}}$
1.0
1.2
1.4
1.6
1.8
b = .30
SAND No. 32

RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO



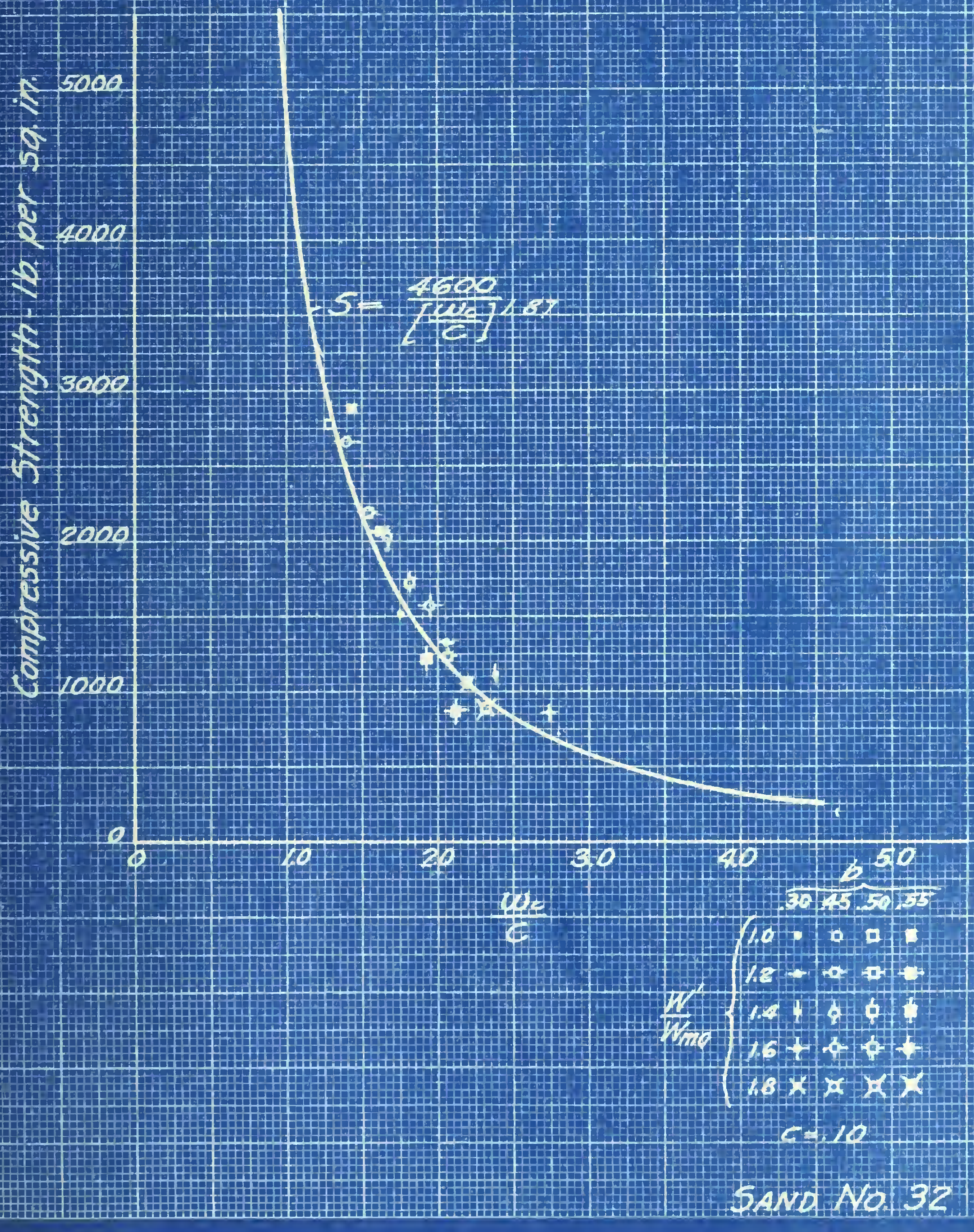

RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
$S = \frac{4600}{\left[\frac{w_c}{c}\right]^{1.87}}$
0
1.0
2.0
3.0
4.0
5.0
$\frac{w_c}{c}$
c
.06 .10 .15
$\frac{W'}{W_{mo}}$
1.0
1.2
1.4
1.6
1.8
b = 50
SAND NO. 32

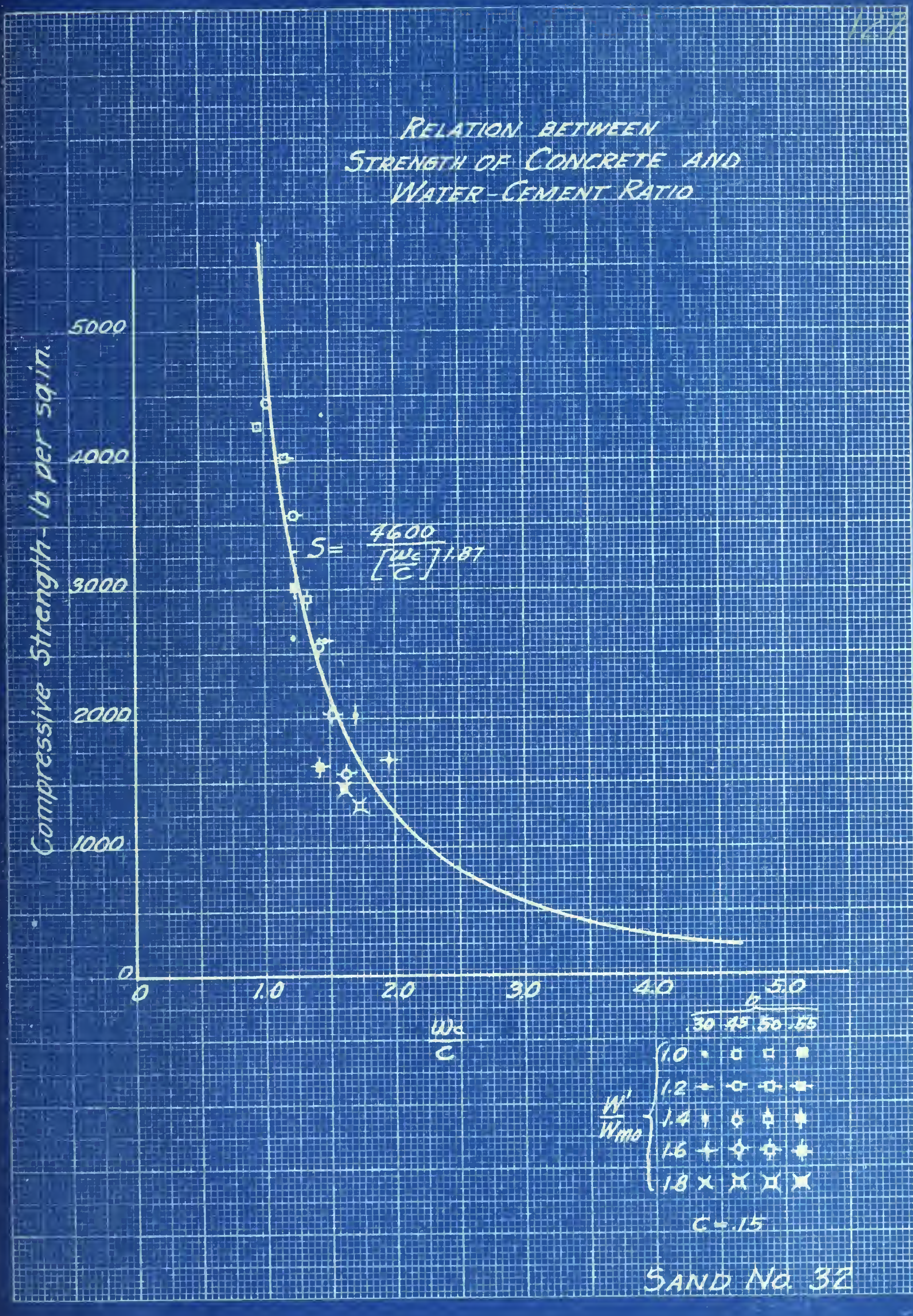

RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
Compressive Strength- lb. per sq. in.
5000
4000
3000
2000
1000
0
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
c
.06 .10 .15
1.0
1.2
1.4
1.6
1.8
$\frac{W'}{W_{mo}}$
b = .55
SAND No. 32

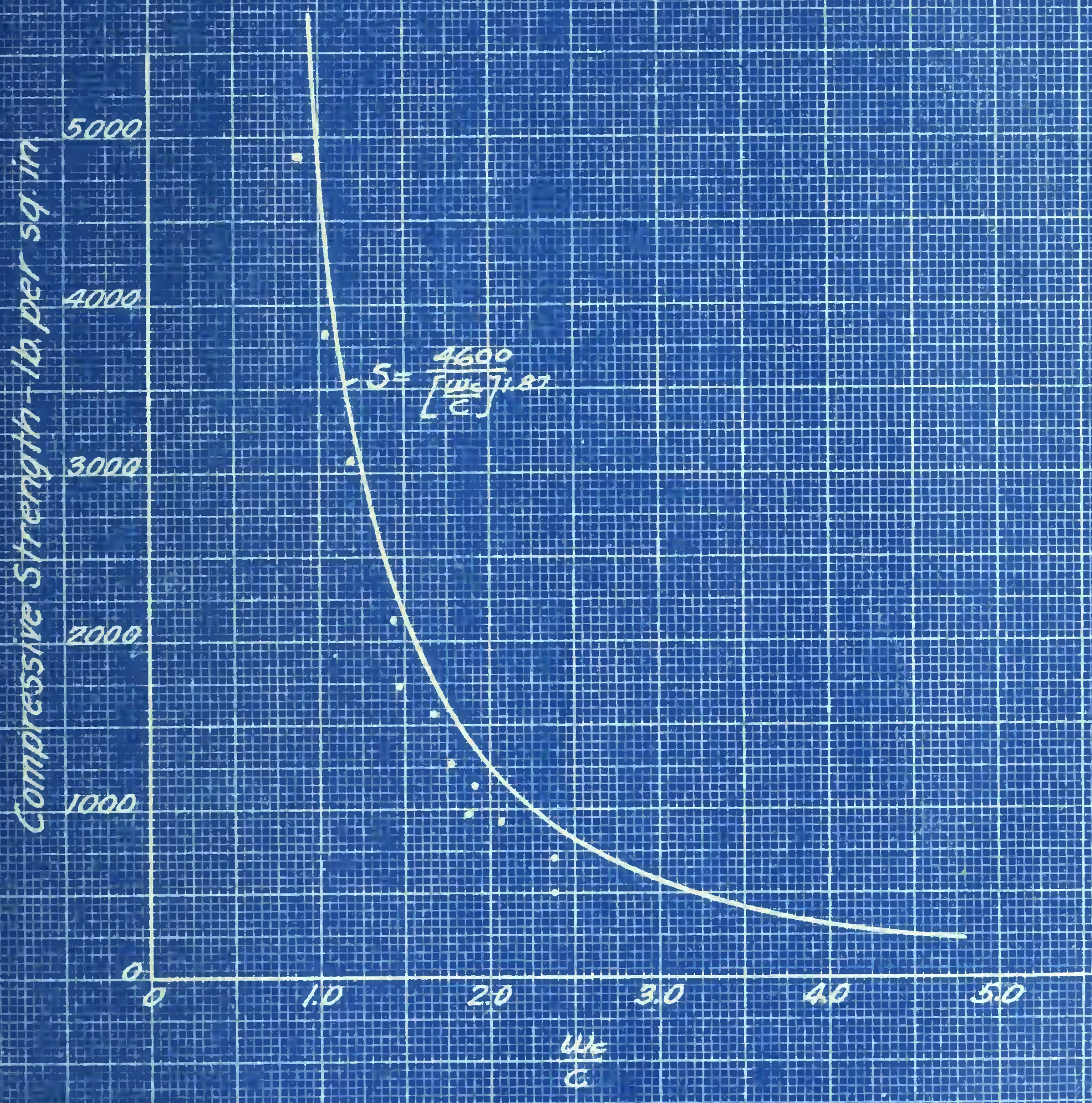


125
RELATION BETWEEN
WATER-CEMENT RATIO AND
STRENGTH OF CONCRETE
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
b
30 45 50
$\frac{W'}{W_{mo}}$
1.0
1.2
1.4
1.6
1.8
C = .06
SAND No. 32

RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO

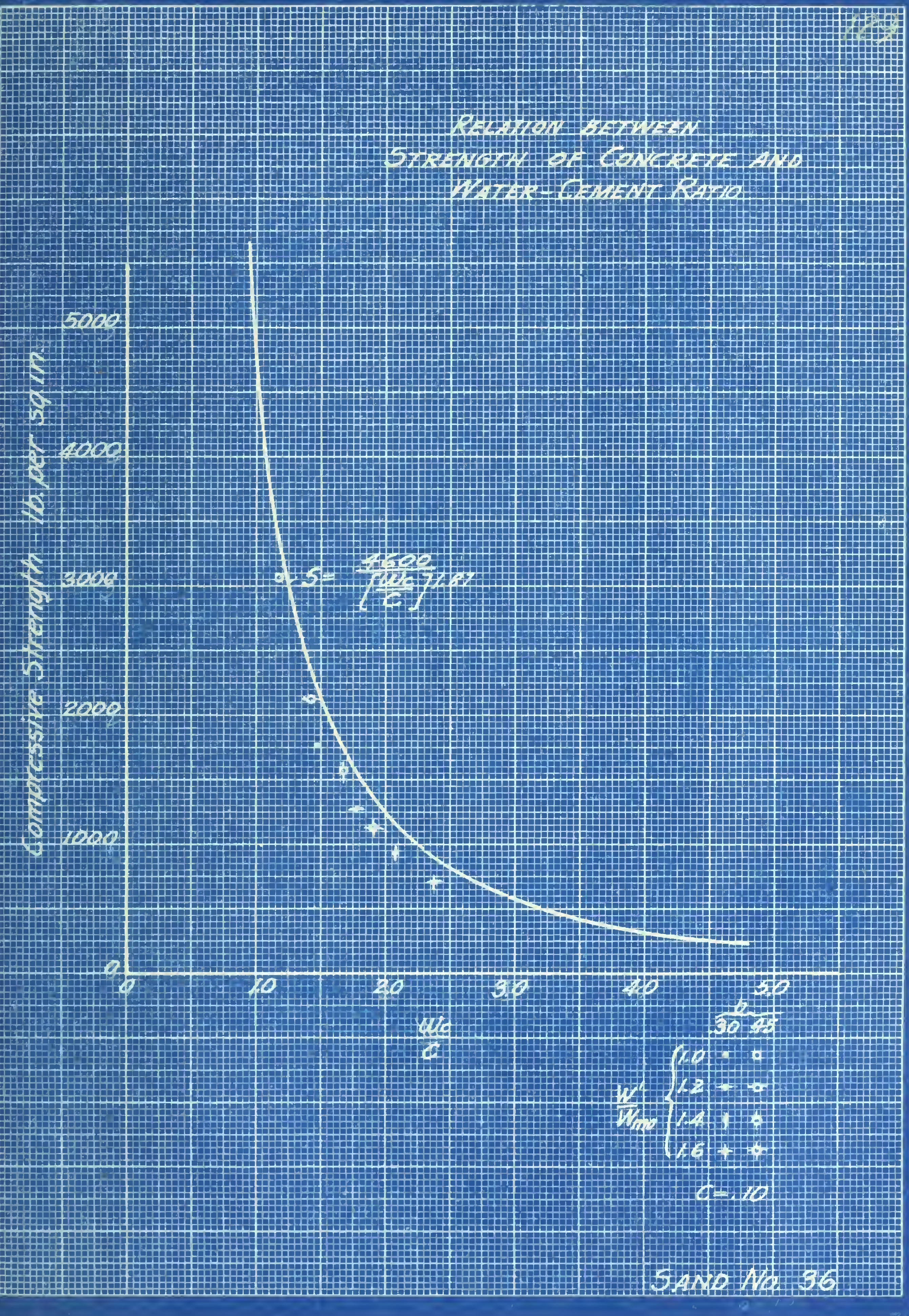


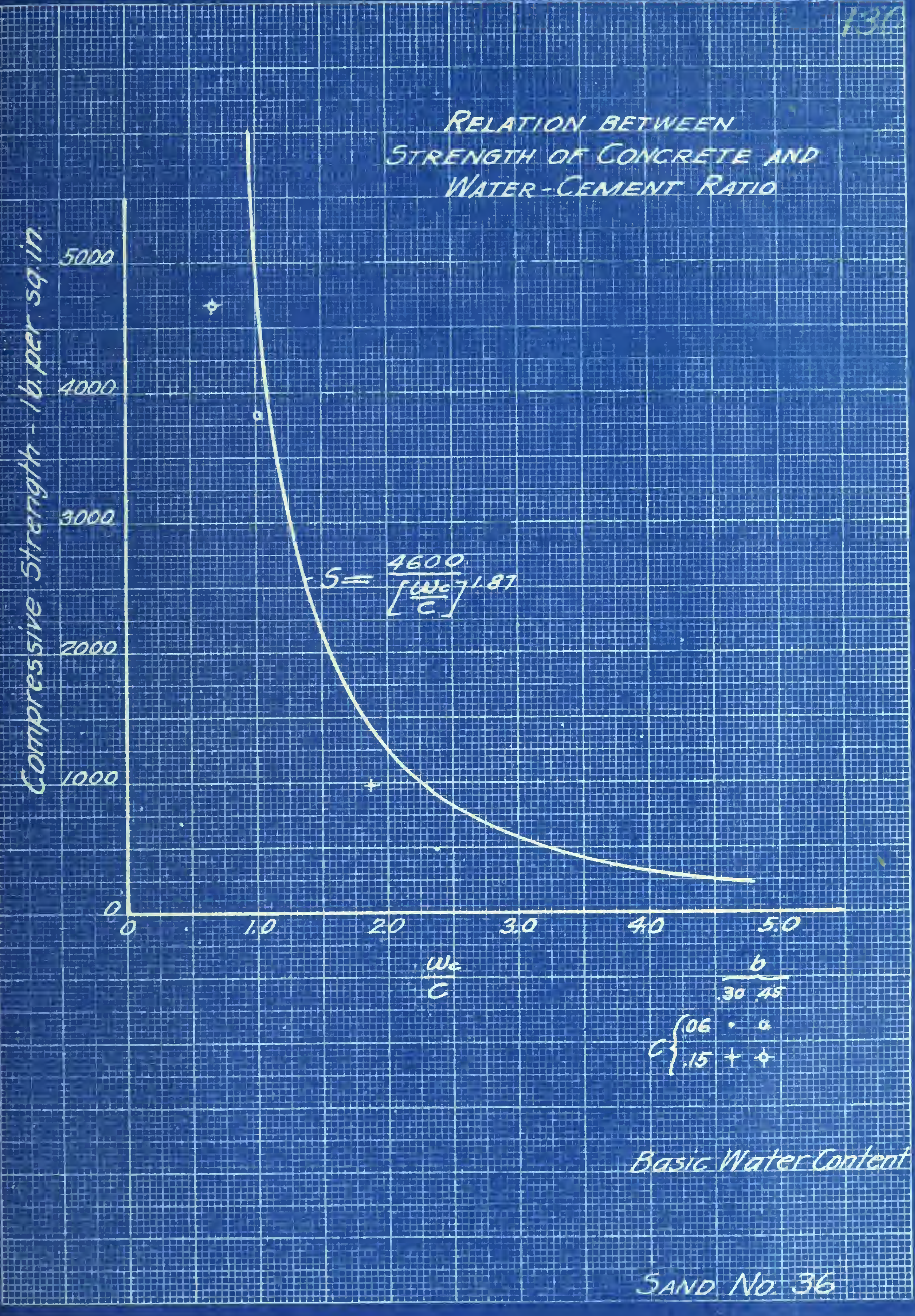

RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
Compressive Strength - lb per sq.in.
5000
4000
3000
2000
1000
0
S = 4600 / [Wc/C]^1.87
0
1.0
2.0
3.0
4.0
5.0
Wc/C
b
.30 .45 .50 .55
W'/Wmo
1.0
1.2
1.4
1.6
1.8
C = 1:5
SAND No. 32



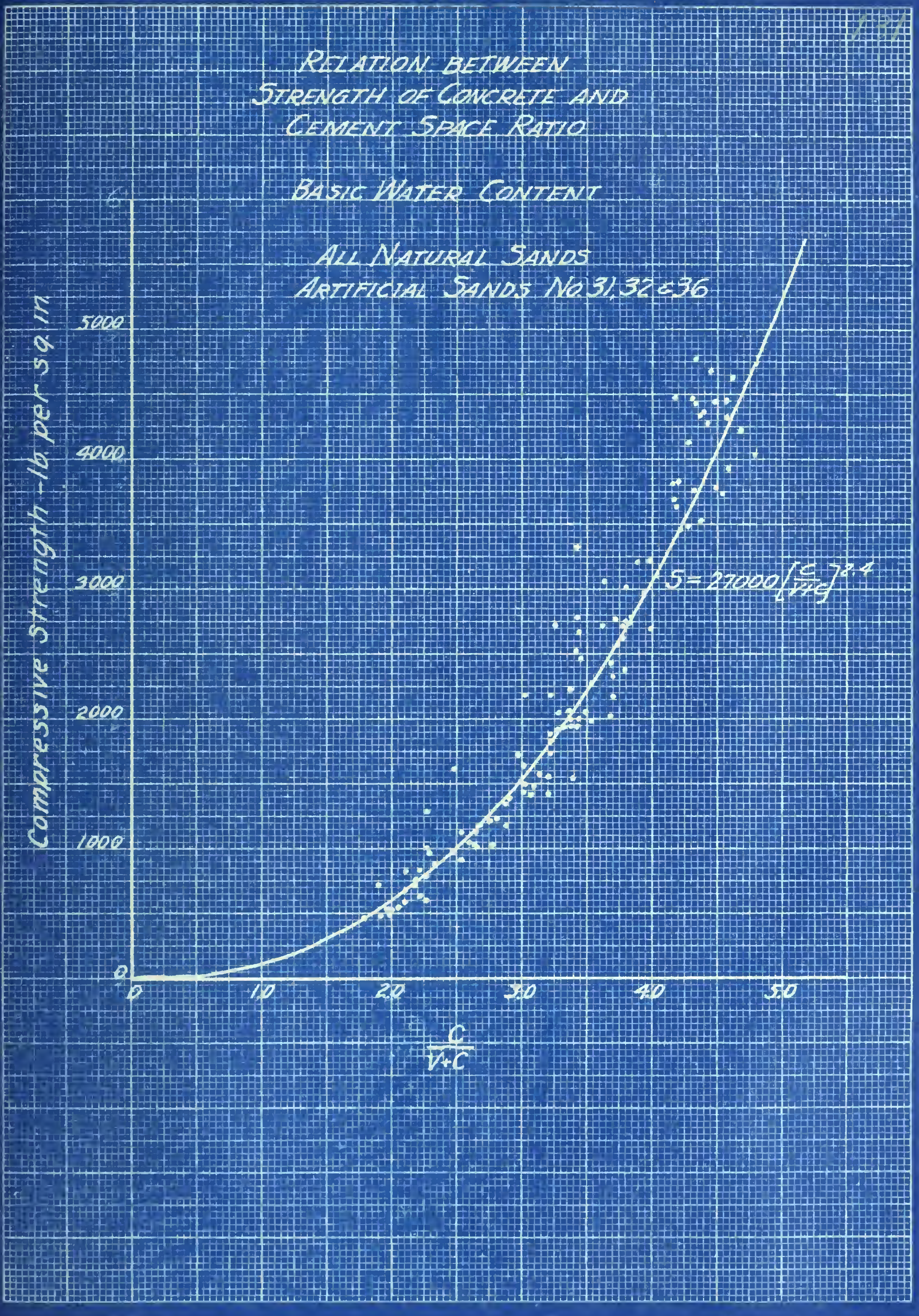
RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO

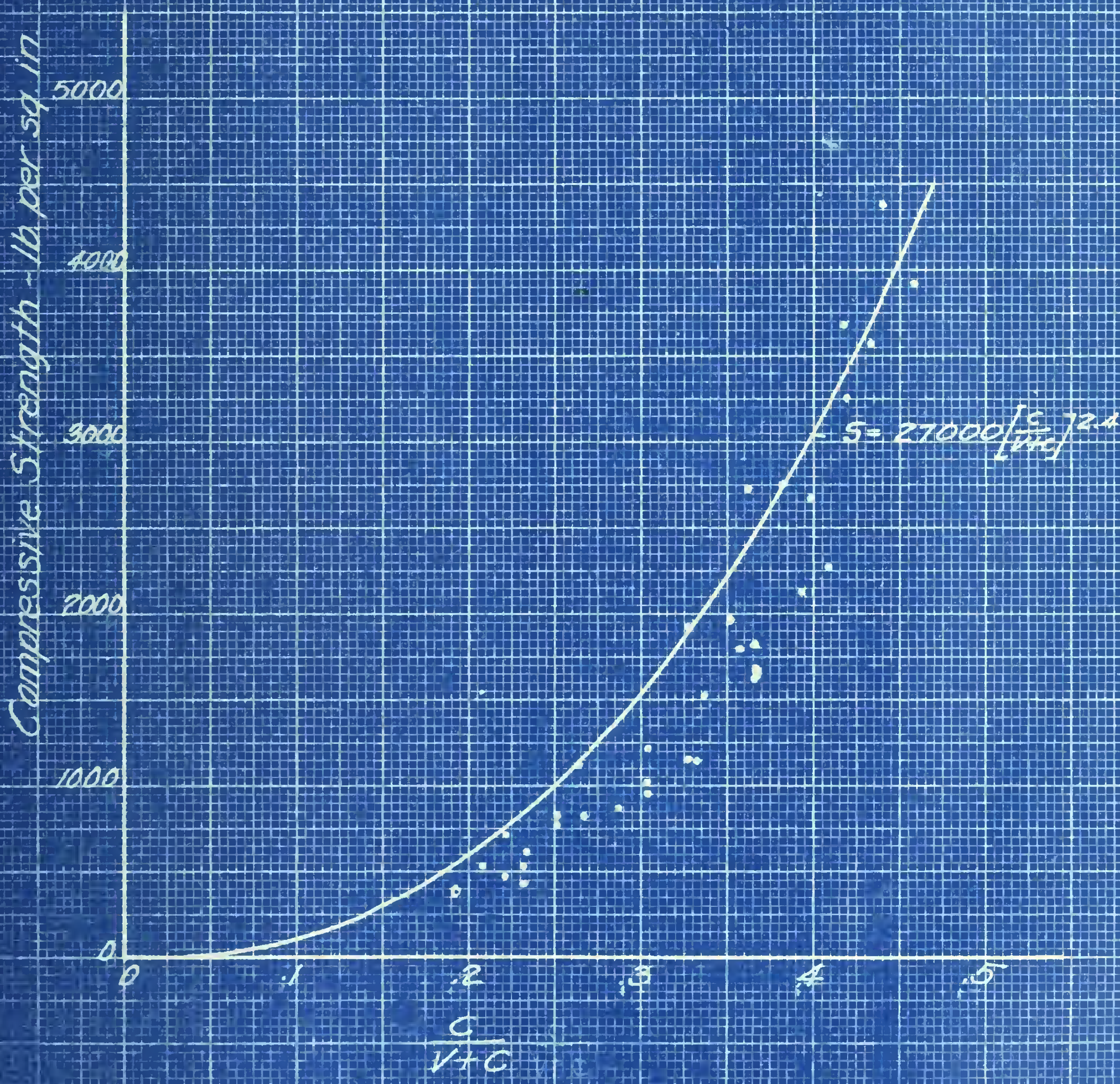
SAND NO. 36


RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
Compressive Strength lb. per sq. in.
5000
4000
3000
2000
1000
0
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
0
1.0
2.0
3.0
4.0
5.0
$\frac{W_c}{C}$
b
.30
.45
1.0
1.2
1.4
1.6
$\frac{W'}{W_{mo}}$
C = .10
SAND No. 36



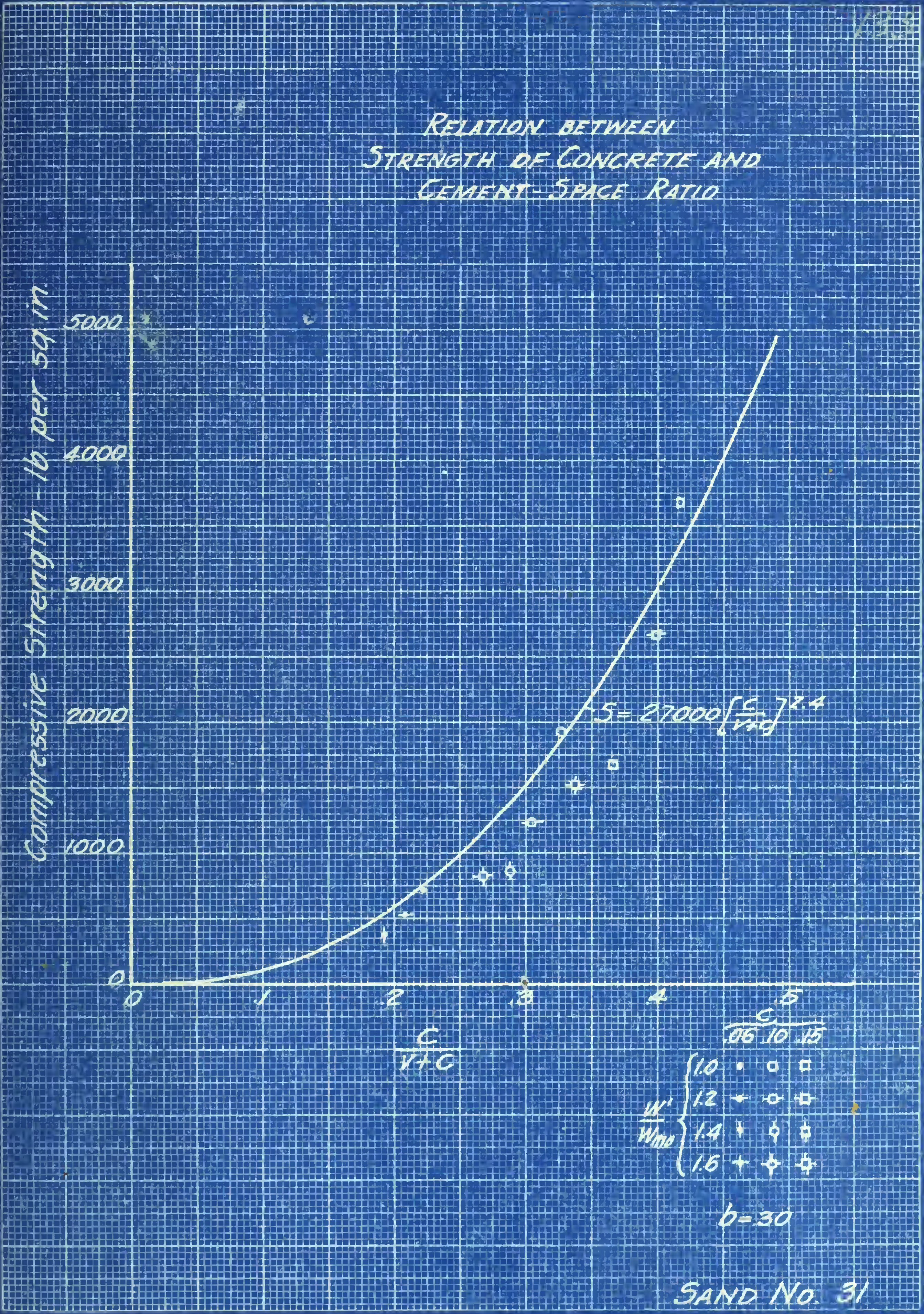
RELATION BETWEEN
STRENGTH OF CONCRETE AND
WATER-CEMENT RATIO
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
$S = \frac{4600}{\left[\frac{W_c}{C}\right]^{1.87}}$
$\frac{W_c}{C}$
b
.30 .45
C .06
C .15
Basic Water Content
SAND No. 36

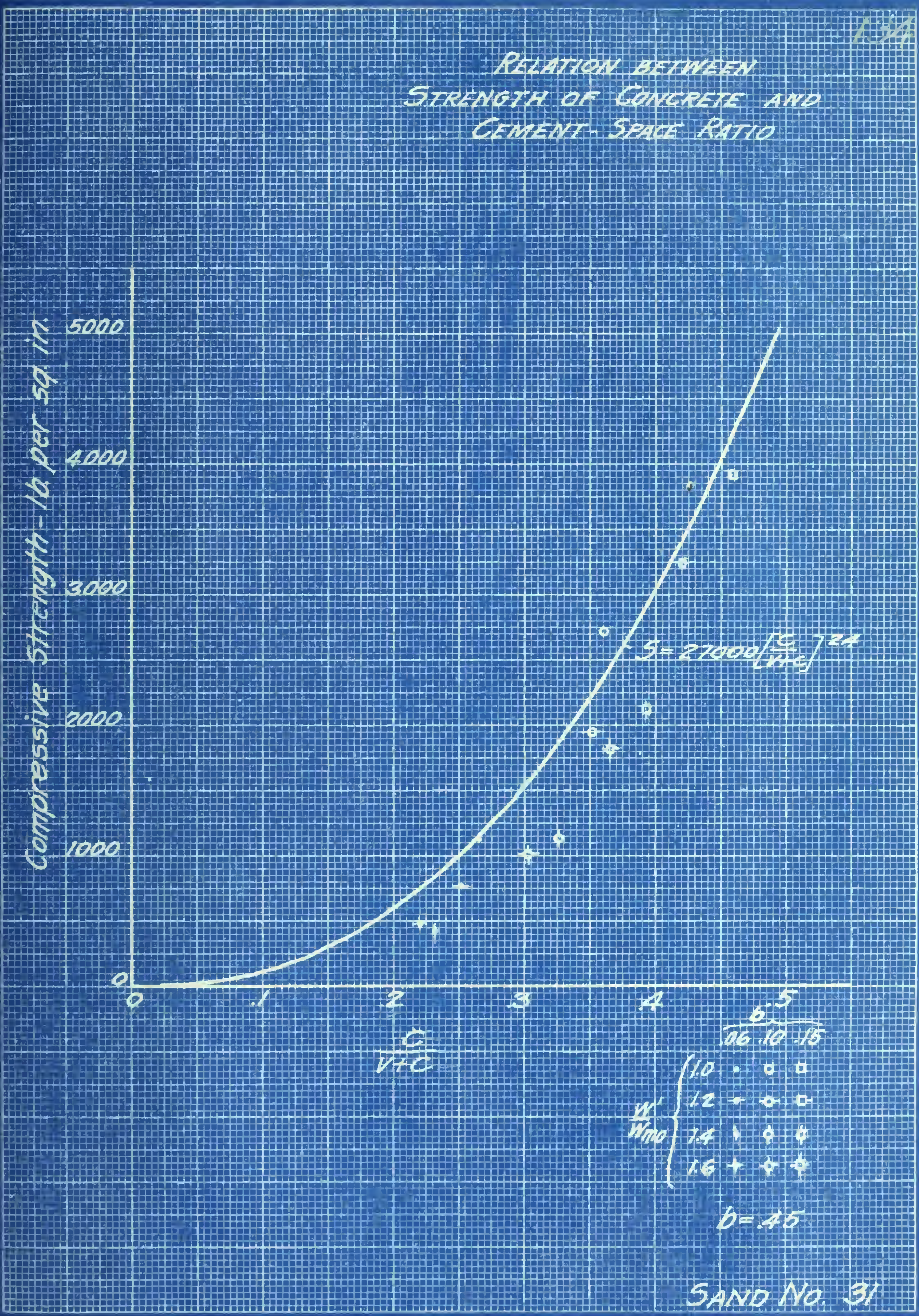

RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT SPACE RATIO
BASIC WATER CONTENT
ALL NATURAL SANDS
ARTIFICIAL SANDS No. 31, 32 & 36
Compressive Strength - lb per sq in
5000
4000
3000
2000
1000
0
0
1.0
2.0
3.0
4.0
5.0
$S = 27000\left[\frac{C}{V+C}\right]^{2.4}$
$\frac{C}{V+C}$

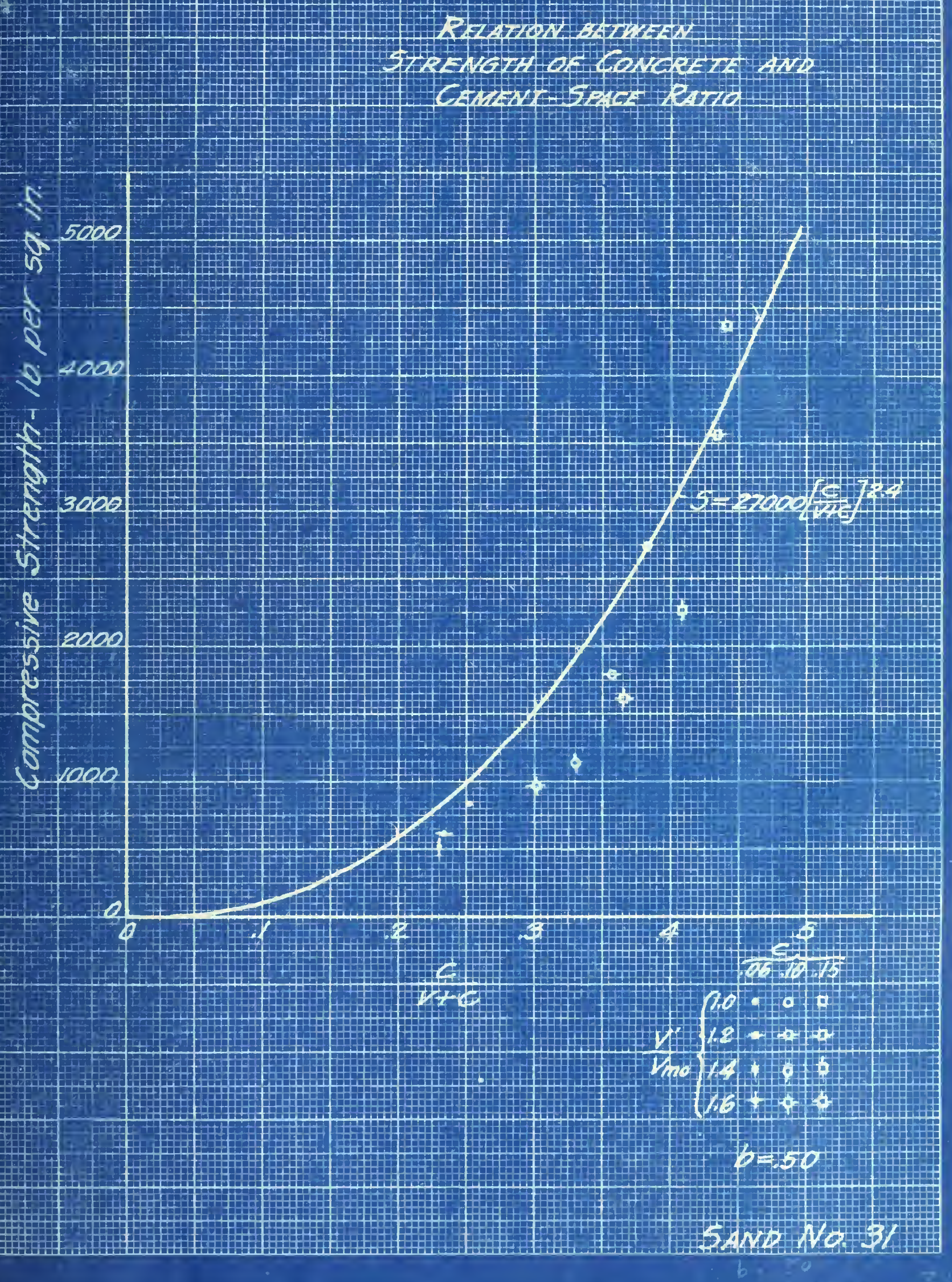


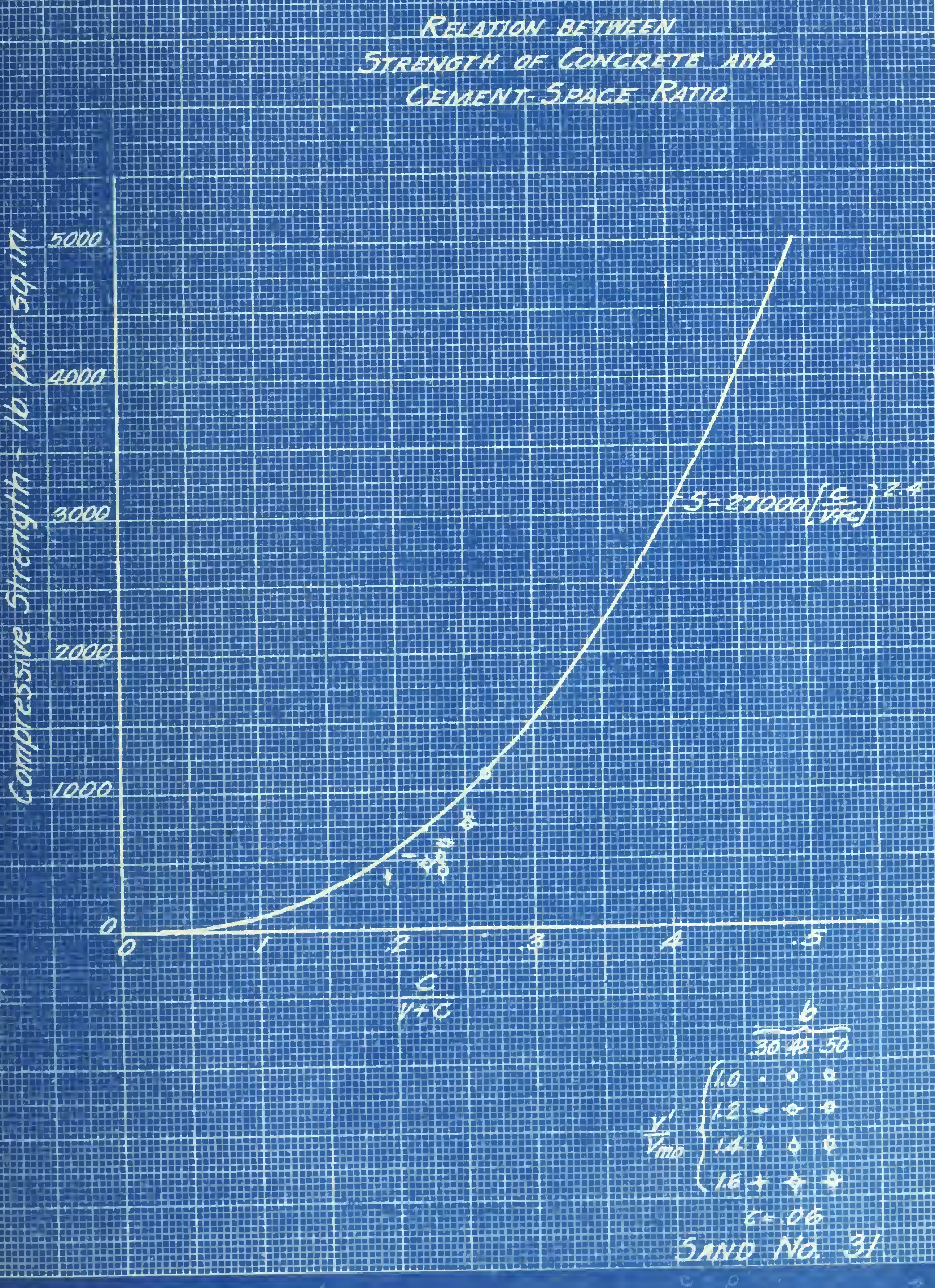
RELATION BETWEEN
STRENGTH OF CONCRETE AND CEMENT-SPACE RATIO

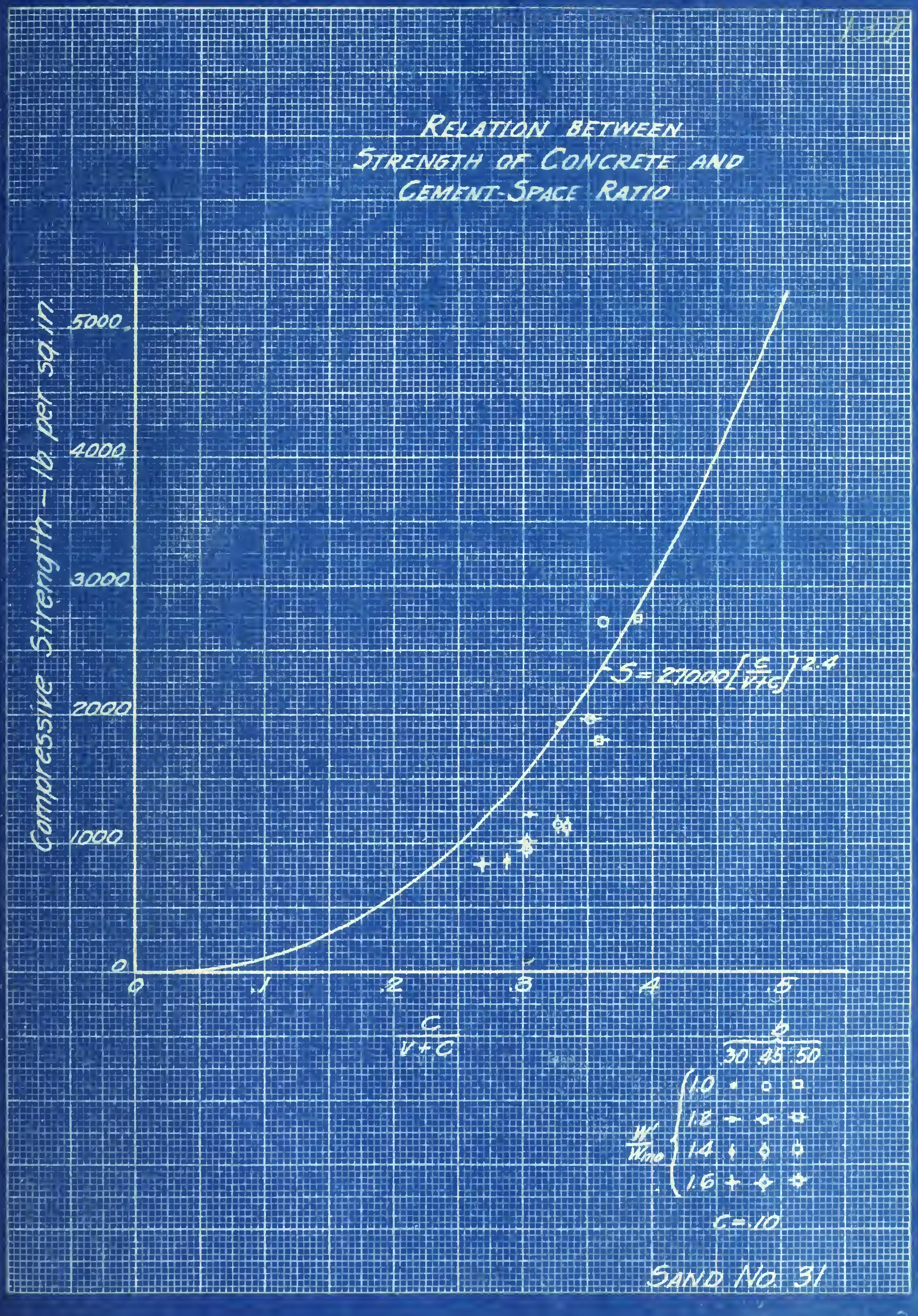
SAND No. 31

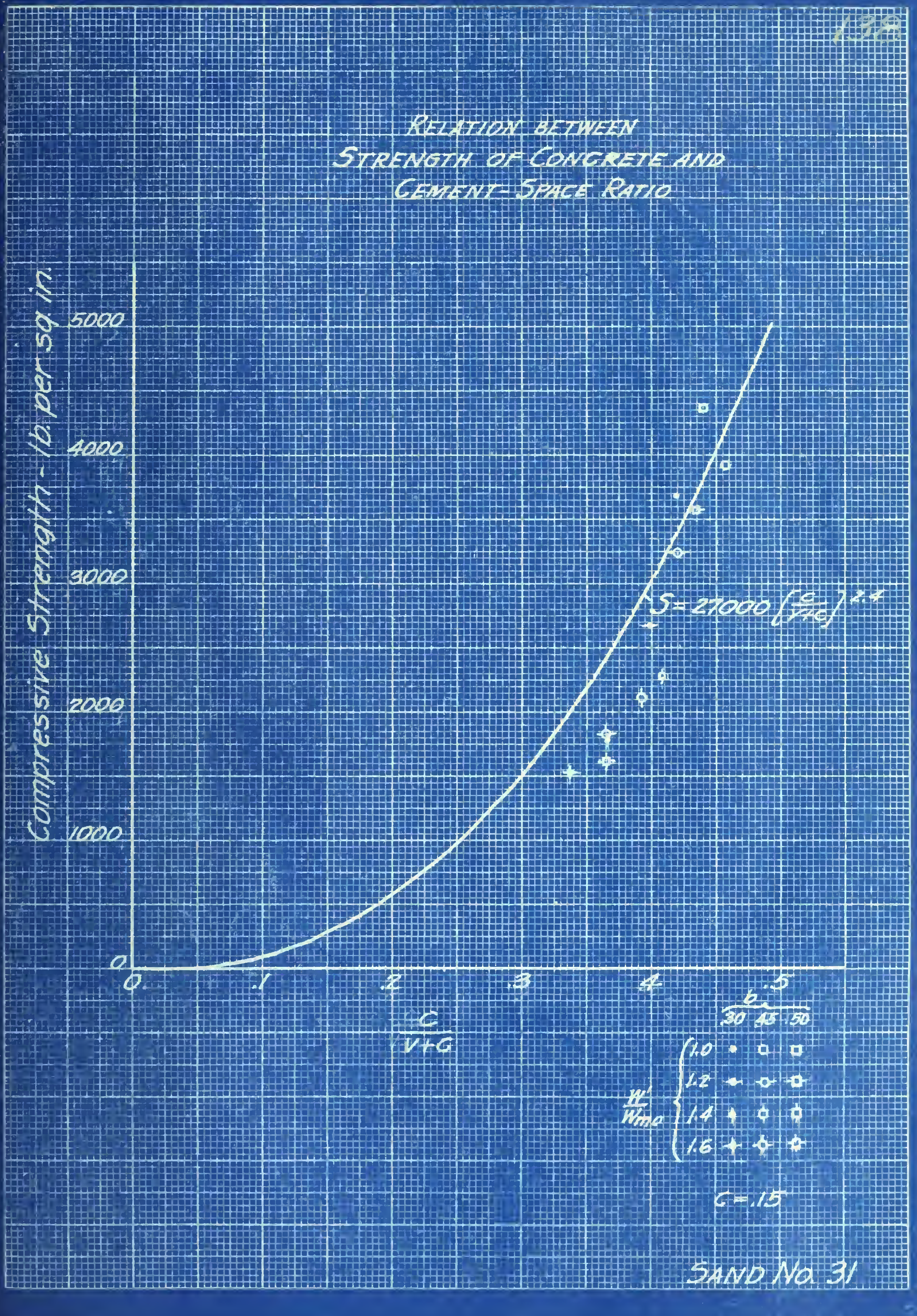

RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
0
.1
.2
.3
.4
.5
C / V+C
S=27000 [C / V+C]^2.4
C
.06 .10 .15
W' / Wno
1.0
1.2
1.4
1.6
b=30
SAND No. 31


1-34
Relation between
Strength of Concrete and
Cement-Space Ratio
Compressive Strength - lb per sq. in.
5000
4000
3000
2000
1000
0
0
.1
.2
.3
.4
.5
$S = 27000\left[\frac{c}{v+c}\right]^{2.4}$
$\frac{c}{v+c}$
b
.06 .10 .15
$\frac{W'}{W_{mo}}$
1.0
1.2
1.4
1.6
b=.45
Sand No. 31


RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO
Compressive Strength - lb per sq. in.
5000
4000
3000
2000
1000
0
0
.1
.2
.3
.4
.5
$\frac{c}{v+c}$
$S=27000\left[\frac{c}{v+c}\right]^{2.4}$
c
.06 .10 .15
1.0
1.2
1.4
1.6
$\frac{V'}{V_{mo}}$
b=.50
SAND No. 31

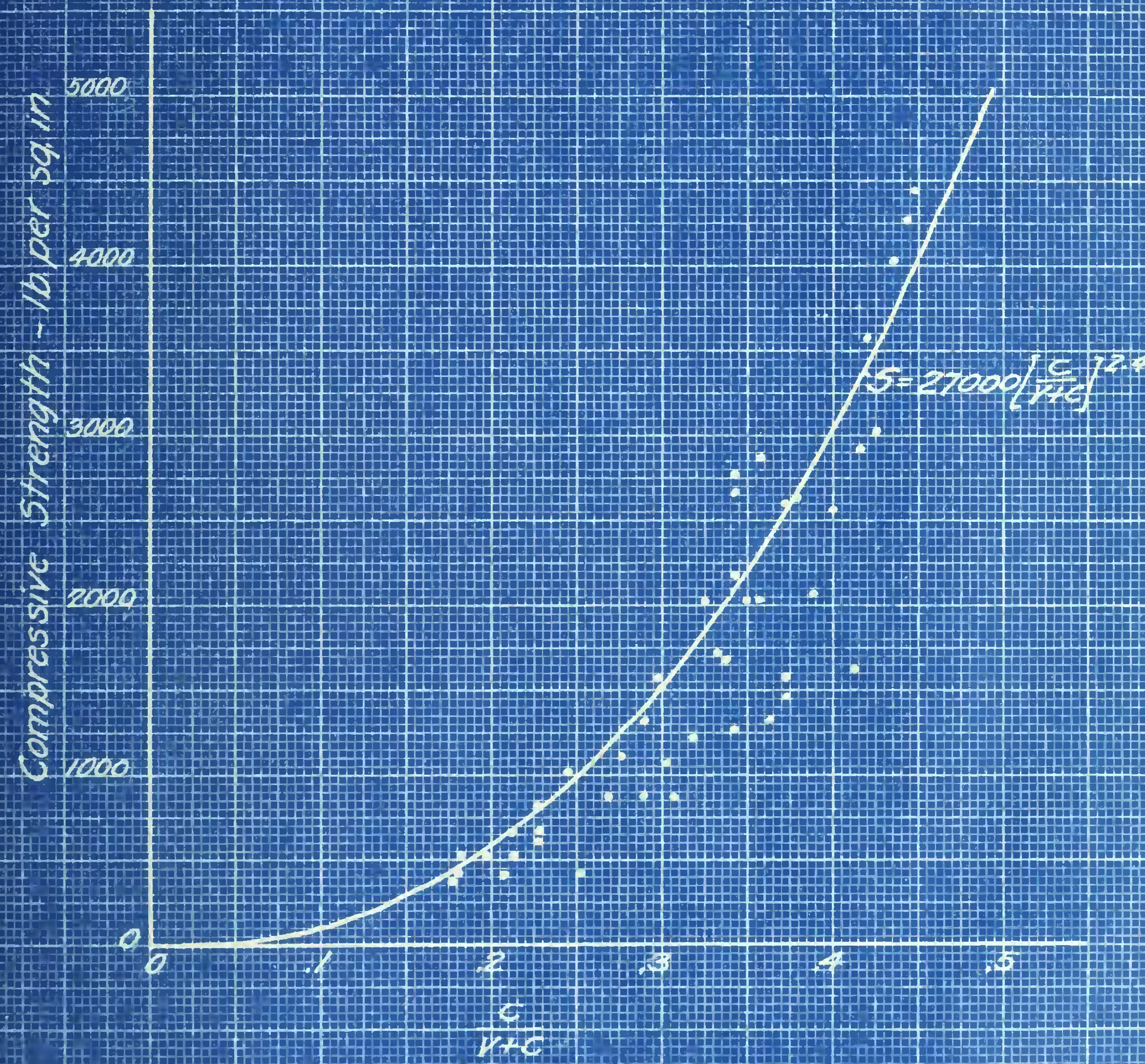

RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
0
.1
.2
.3
.4
.5
C / V+C
S = 27000 [C / V+C]^2.4
b
.30 .45 .50
V' / V_mo
1.0
1.2
1.4
1.6
c = .06
SAND No. 31


137
RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
0
.1
.2
.3
.4
.5
C / V+C
S = 27000 [C / V+C]^2.4
.30 .45 .50
W / Wmo
1.0
1.2
1.4
1.6
C = .10
SAND No. 31



138
RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
0
.1
.2
.3
.4
.5
C / V+C
S = 27000 [C / V+C]^2.4
b
.30 .45 .50
1.0
1.2
1.4
1.6
W' / Wmo
C = .15
SAND No. 31

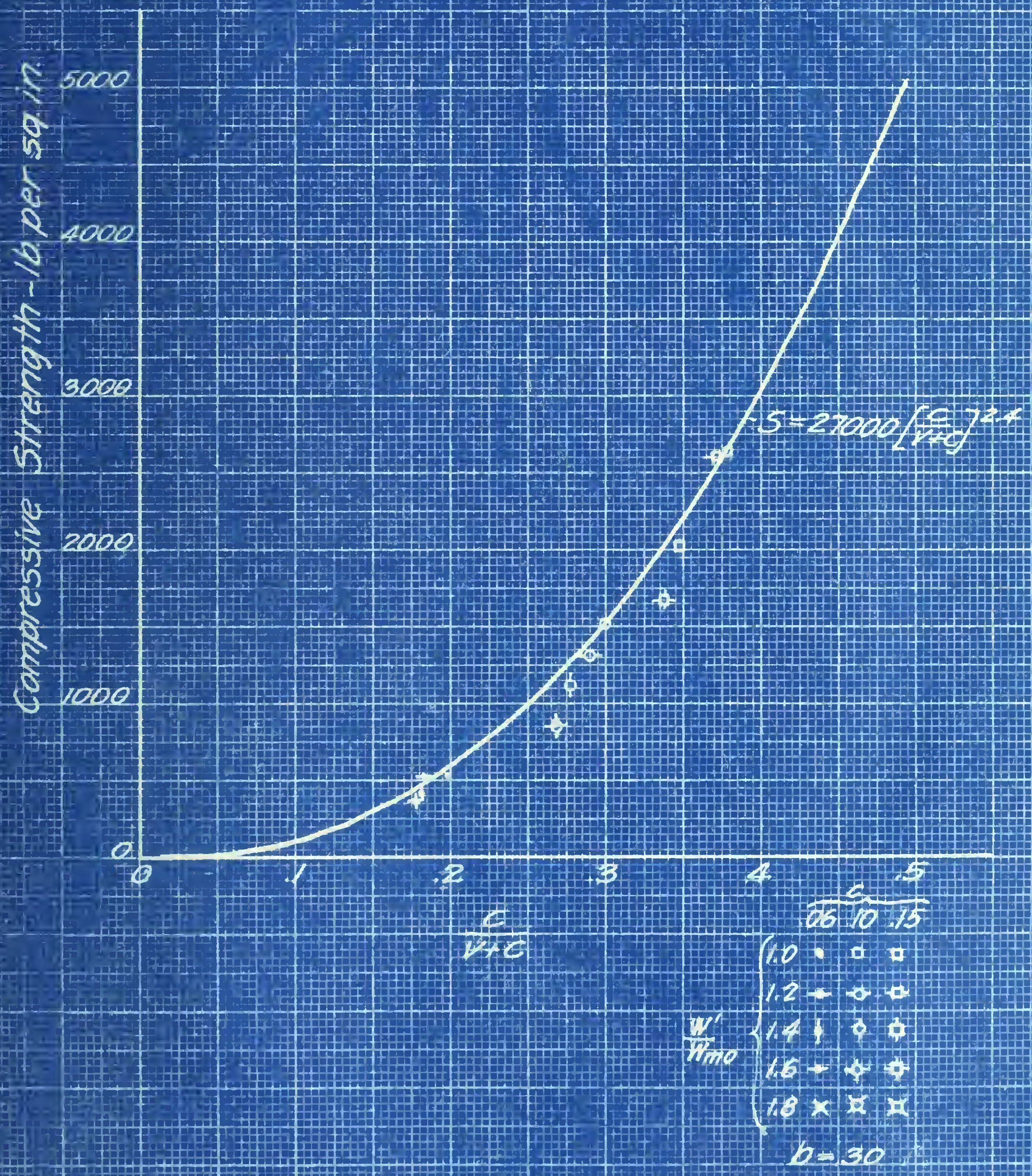
RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO



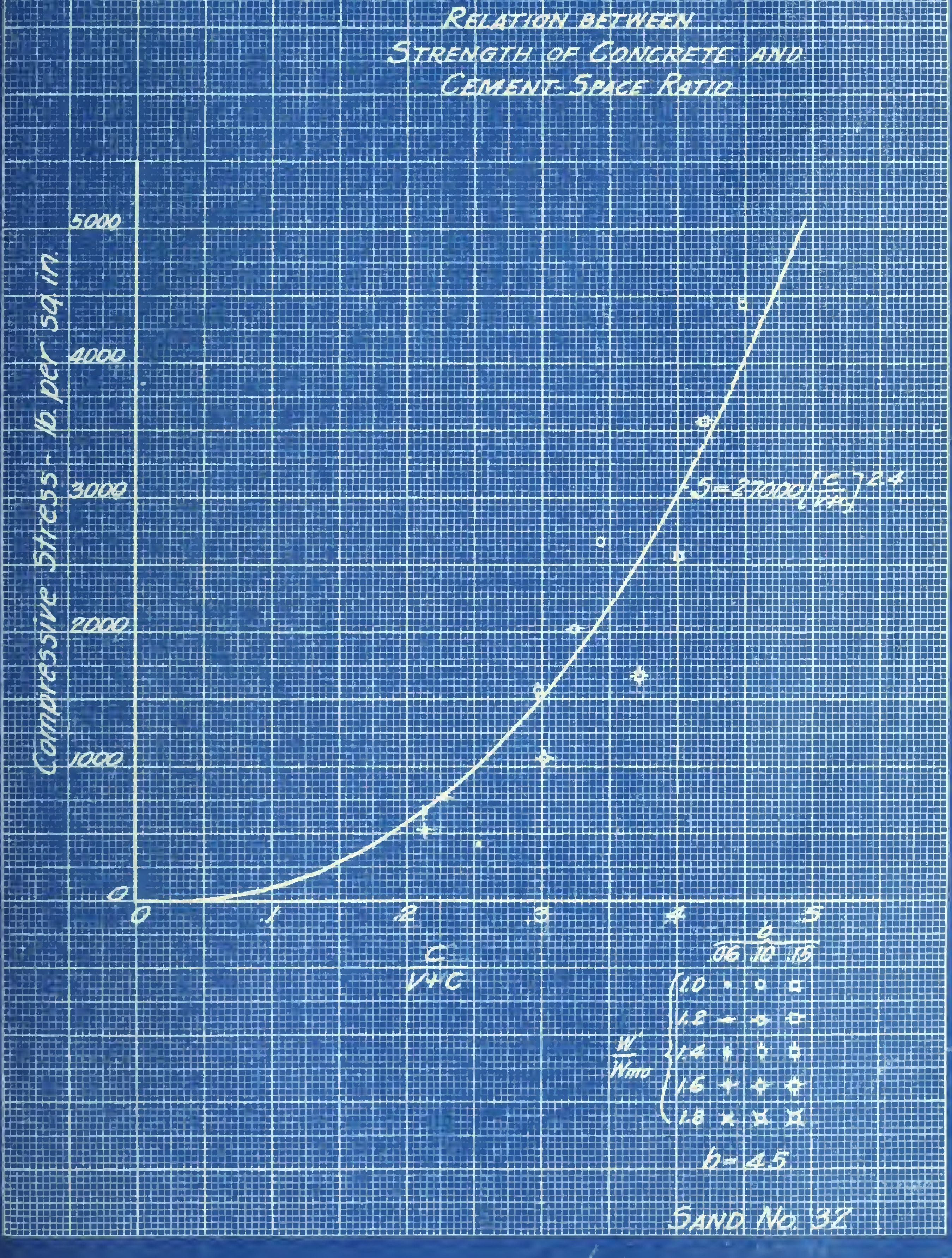
RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO

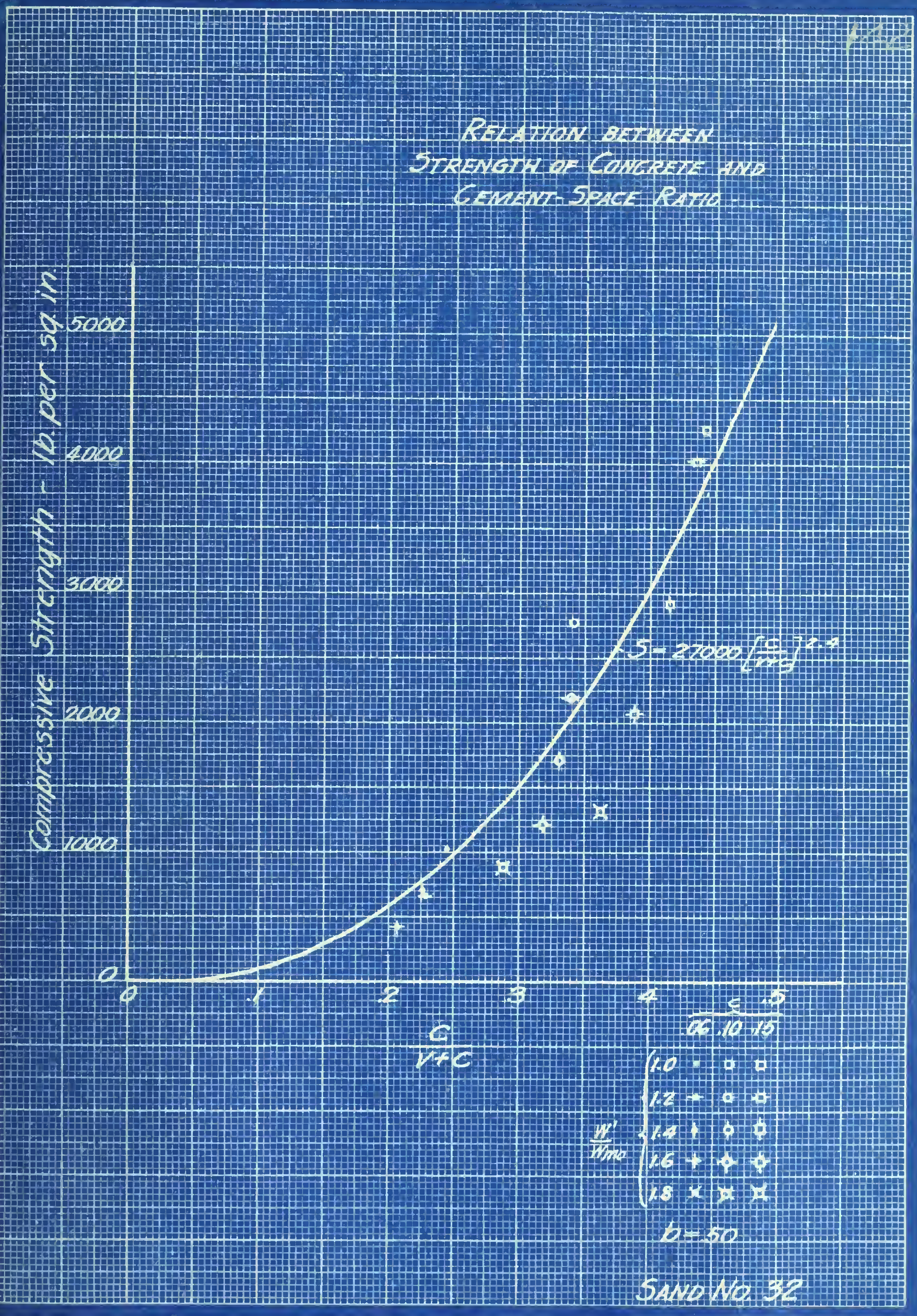
SAND NO. 32

RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO



SAND NO. 32


RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO
Compressive Stress - lb. per sq. in.
5000
4000
3000
2000
1000
0
0
.1
.2
.3
.4
.5
C / V+C
S=27000[C/V+C]^2.4
b
.06
.10
.15
W / Wmo
1.0
1.2
1.4
1.6
1.8
b=4.5
SAND No. 32


RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
0
.1
.2
.3
.4
.5
C
V+C
S=27000 [C/(V+C)]^2.4
c
.06 .10 .15
1.0
1.2
1.4
1.6
1.8
W'/Wmo
b=.50
SAND NO. 32

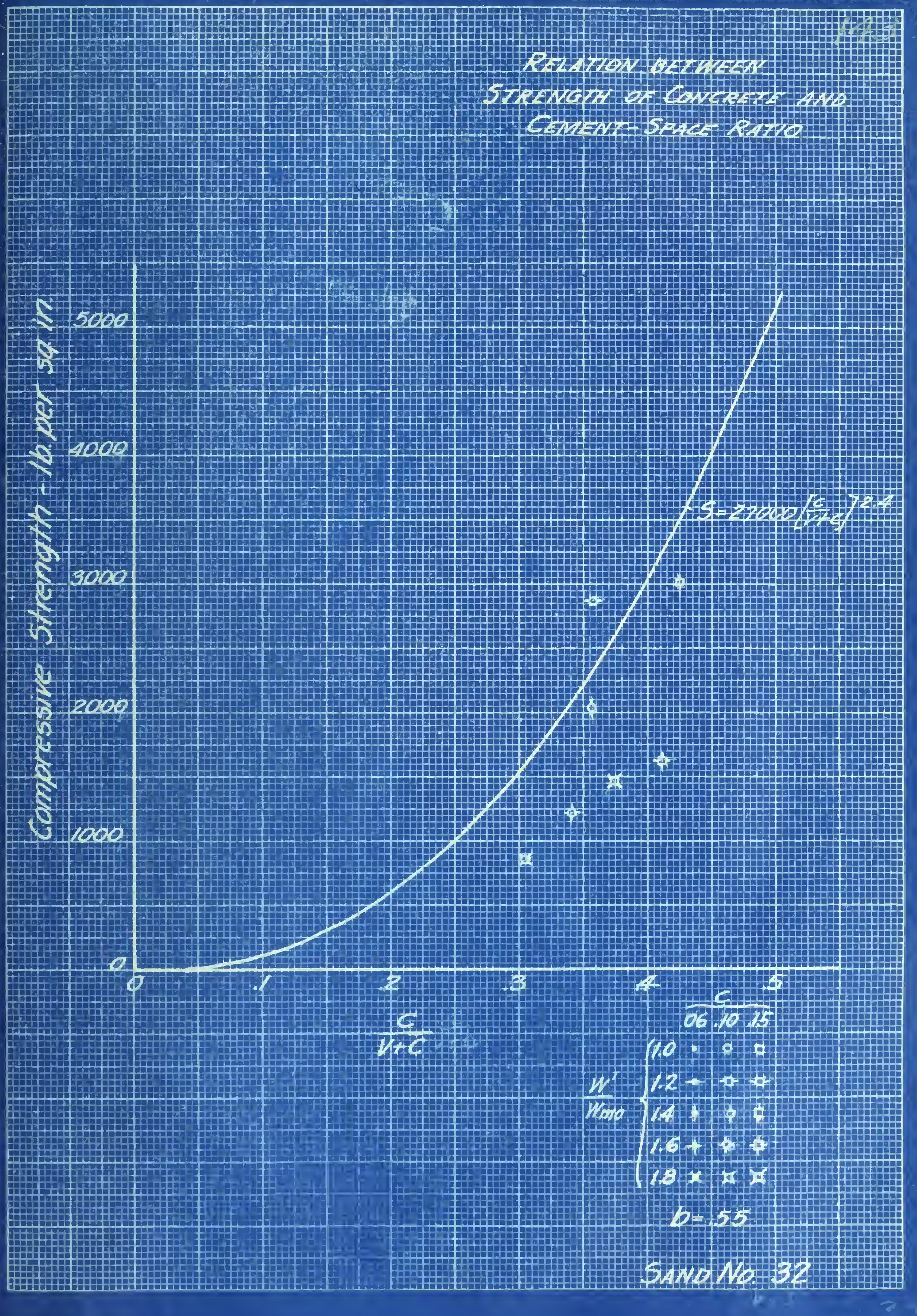
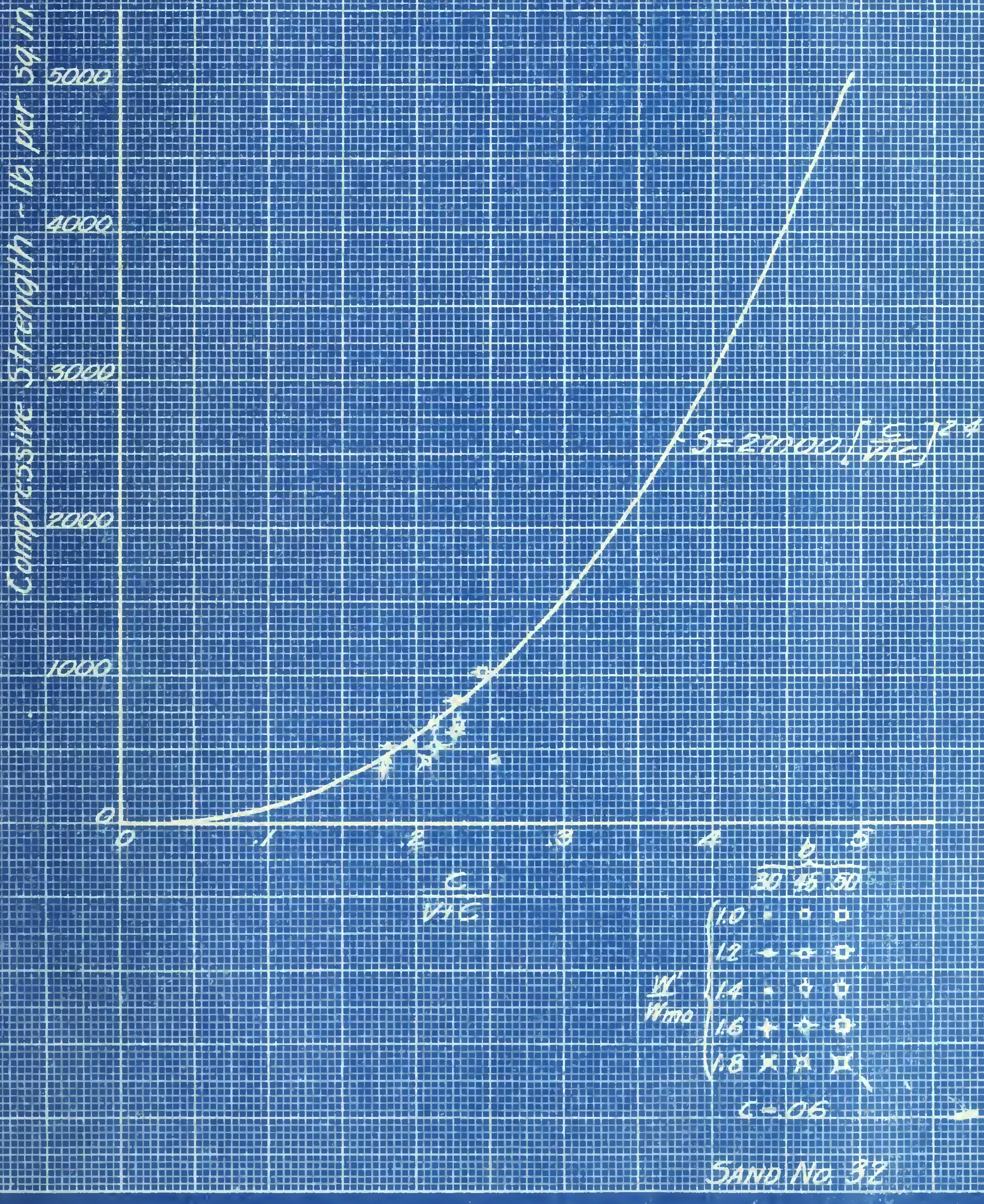
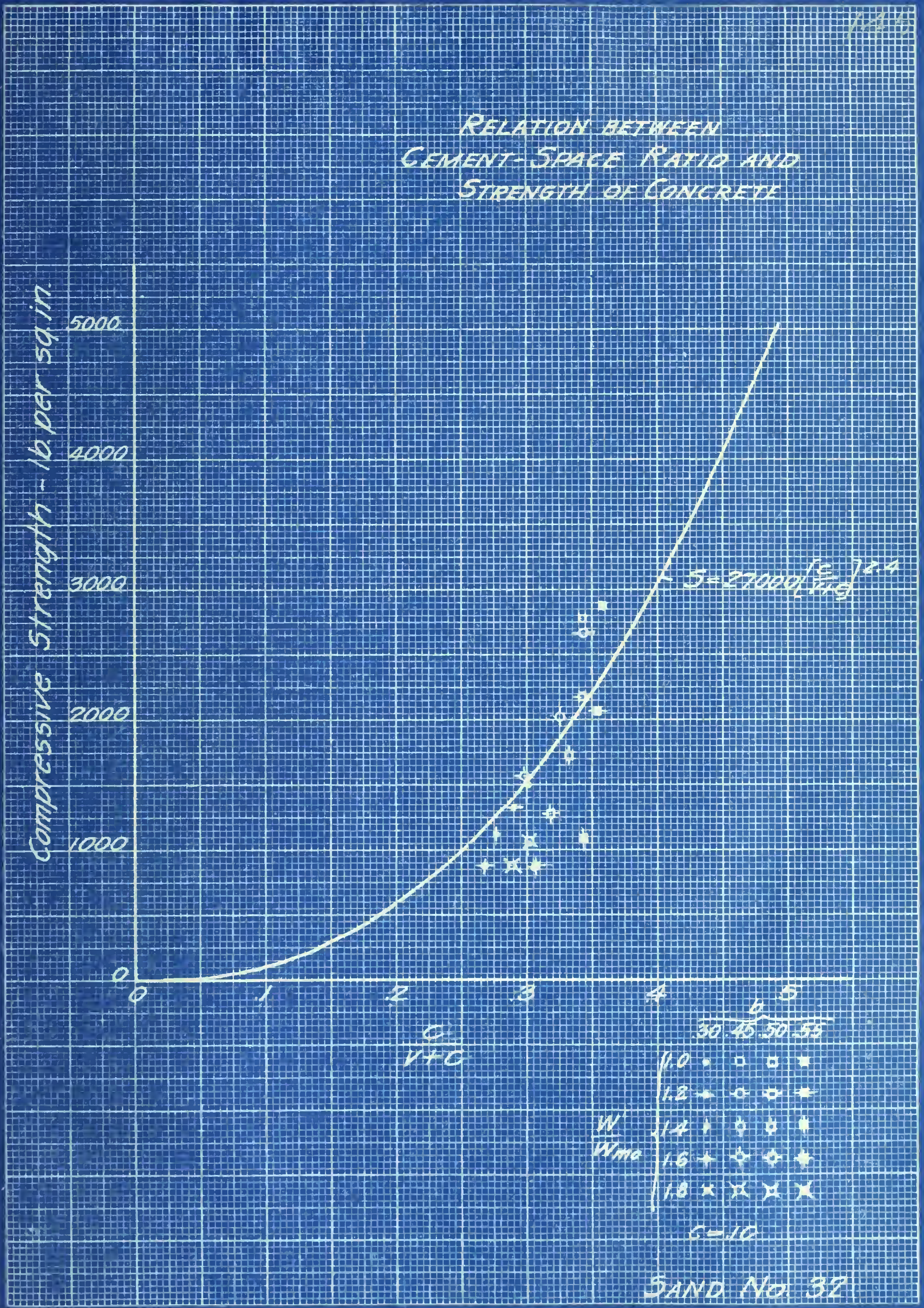


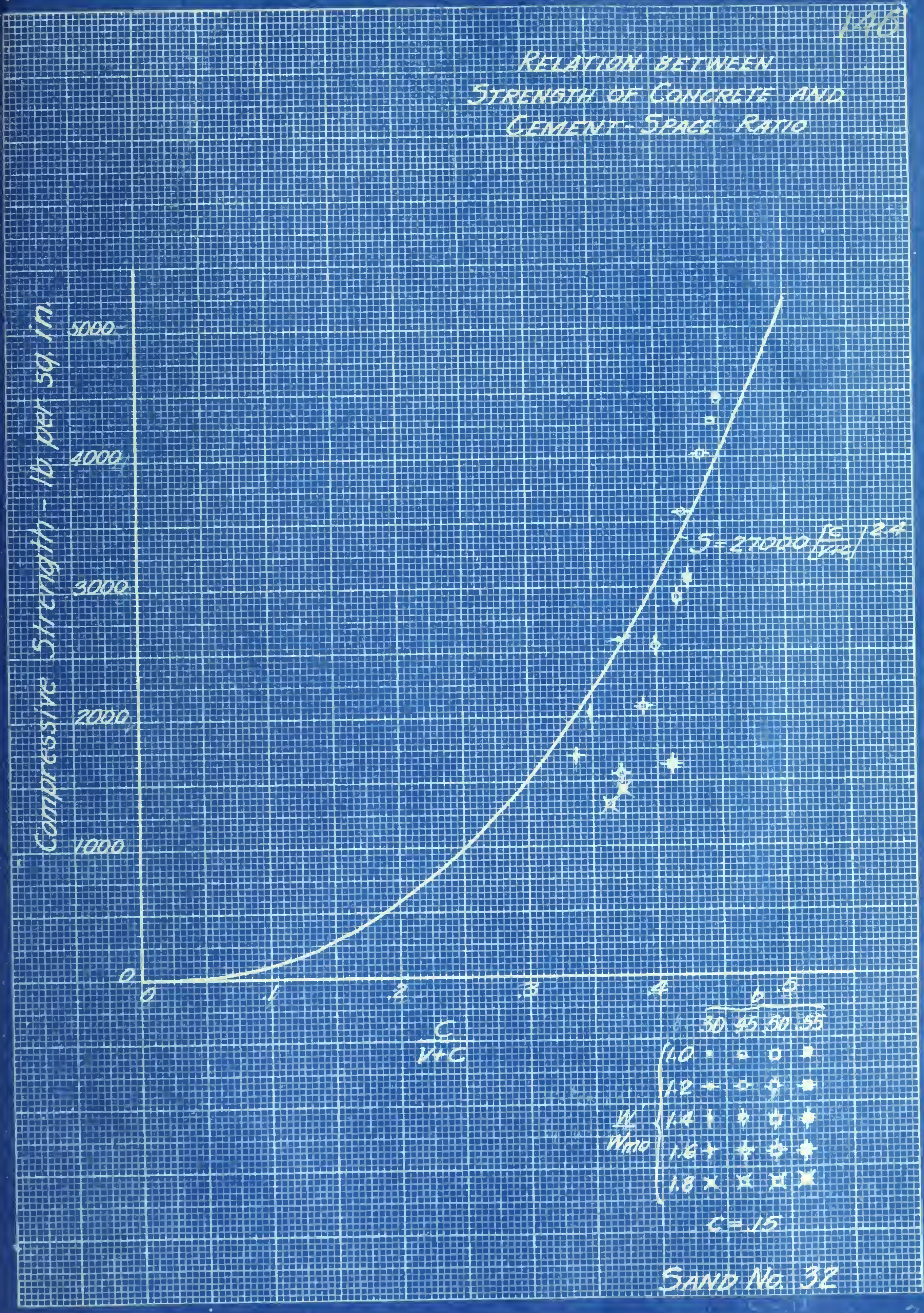
Fig. 3
RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO
Compressive Strength - lb. per sq. in.
5000
4000
3000
2000
1000
0
0
.1
.2
.3
.4
.5
C / V+C
$S=27000\left[\frac{c}{v+c}\right]^{2.4}$
c
.06 .10 .15
W' / Wmo
1.0
1.2
1.4
1.6
1.8
b = .55
SAND No. 32

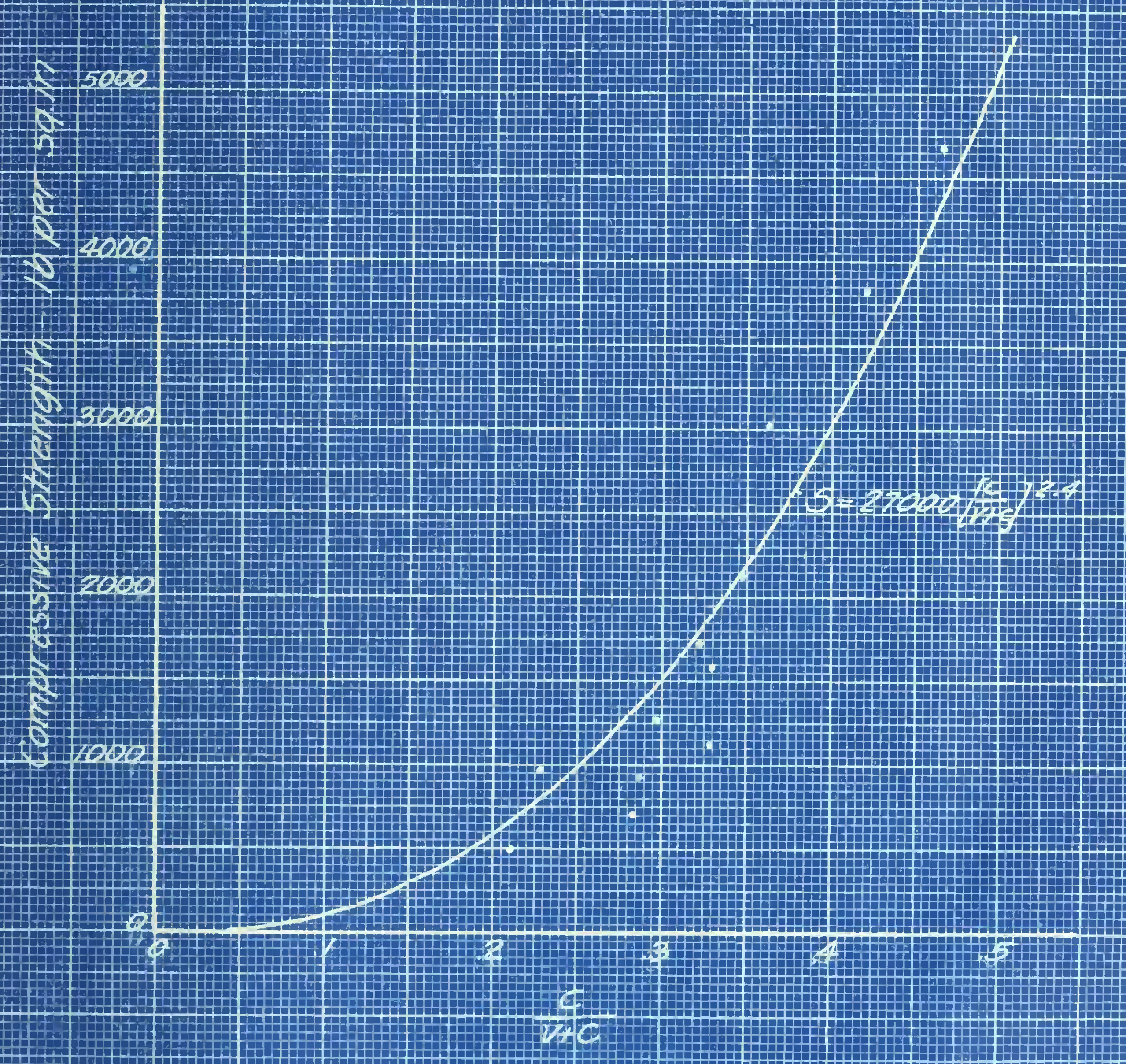
RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO





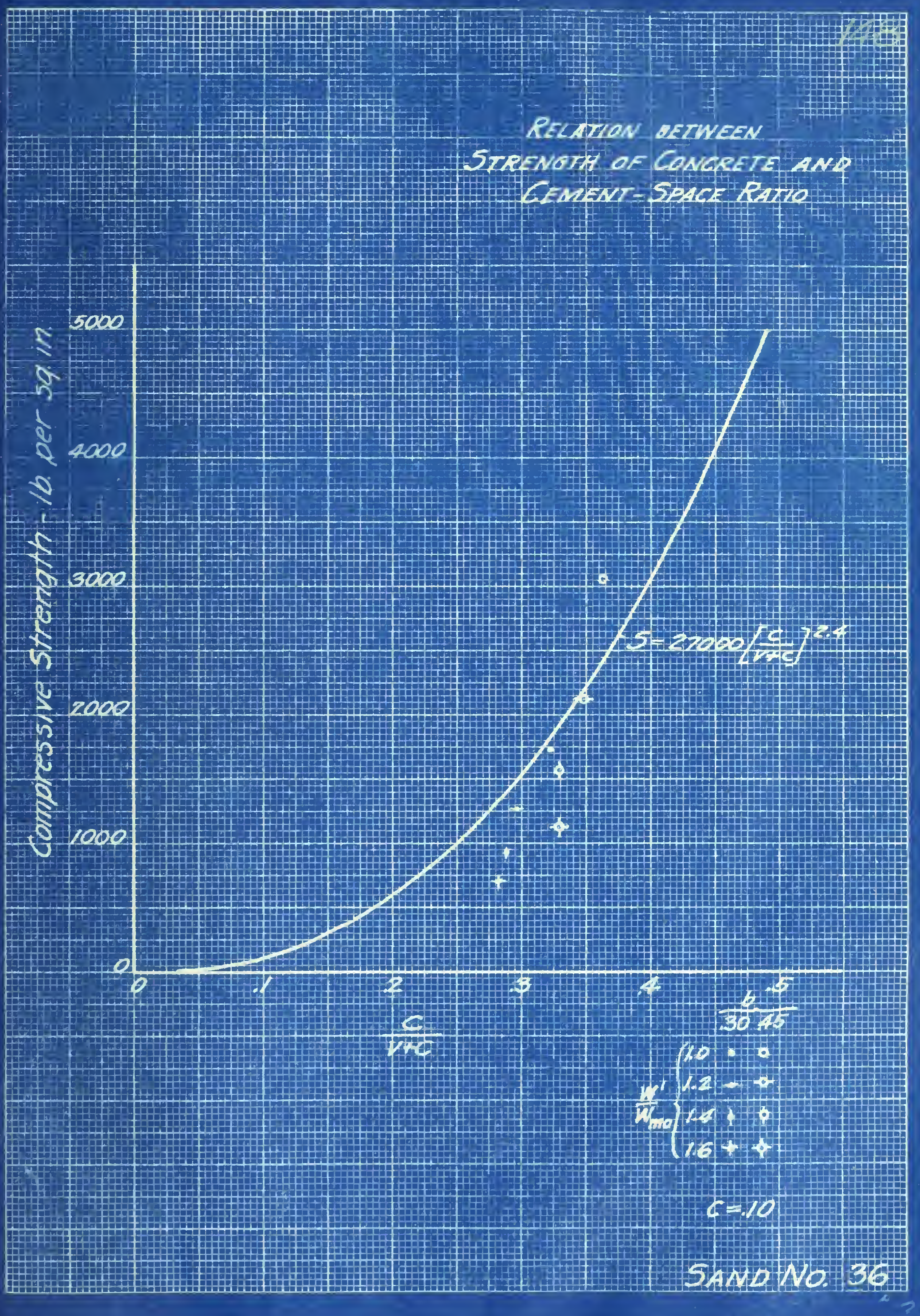
RELATION BETWEEN
CEMENT-SPACE RATIO AND
STRENGTH OF CONCRETE
Compressive Strength - lb per sq. in.
5000
4000
3000
2000
1000
0
0
.1
.2
.3
.4
.5
$\frac{c}{v+c}$
$S = 27000\left[\frac{c}{v+c}\right]^{2.4}$
b
.30 .45 .50 .55
1.0
1.2
1.4
1.6
1.8
$\frac{W}{W_{mo}}$
c=.10
SAND NO. 32


RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO
Compressive Strength - lb per sq. in.
5000
4000
3000
2000
1000
0
0
.1
.2
.3
.4
.5
.6
$\frac{c}{v+c}$
$S = 27000\left[\frac{c}{v+c}\right]^{2.4}$
b
.30 .45 .50 .55
$\frac{W}{W_{mo}}$
1.0
1.2
1.4
1.6
1.8
c = .15
SAND No. 32



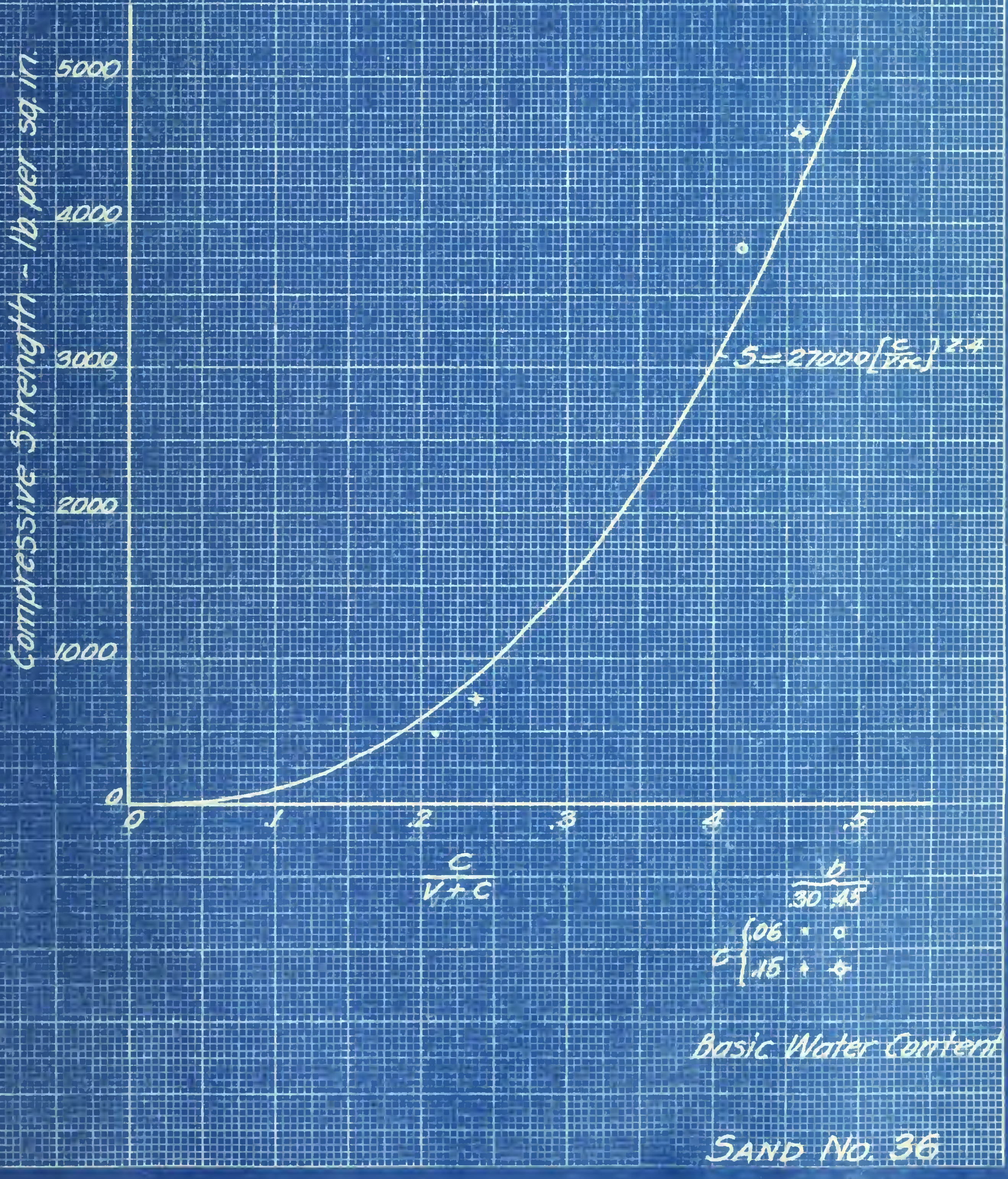
RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO

SAND NO. 36



143
RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO
Compressive Strength - lb per sq in.
5000
4000
3000
2000
1000
0
$S = 27000\left[\frac{C}{VFC}\right]^{2.4}$
0
.1
.2
.3
.4
.5
$\frac{C}{VFC}$
b
.30 .45
$\frac{W^{1}}{W_{ma}}$
1.0
1.2
1.4
1.6
C = .10
SAND No. 36

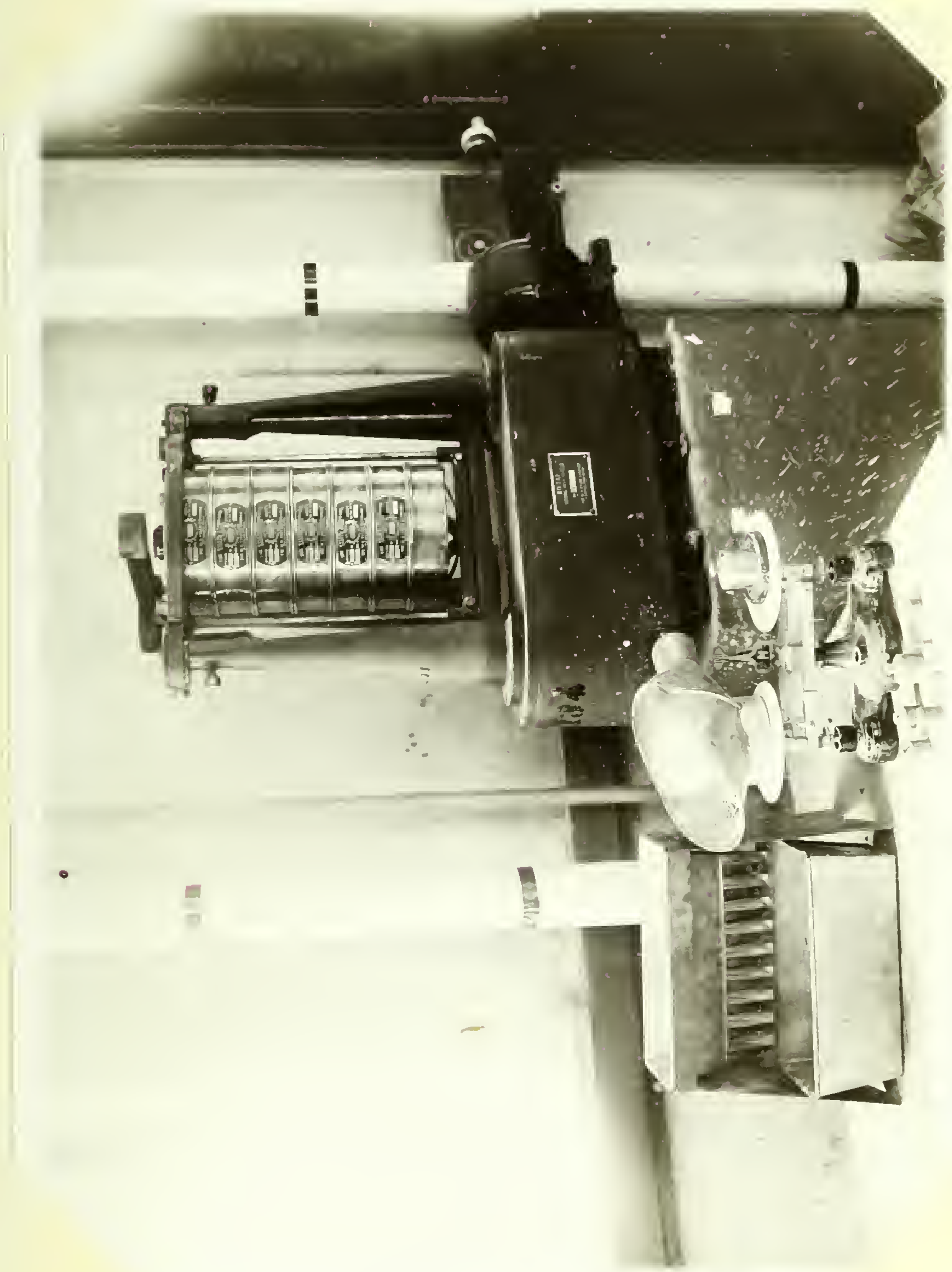
RELATION BETWEEN
STRENGTH OF CONCRETE AND
CEMENT-SPACE RATIO



General View of Apparatus

Ap ratus Used in Mortar Tests

Apparatus Used for Specific Gravity and Absorption Tests



Apparatus for Sieve Analyses

General View of Testing Appar tus

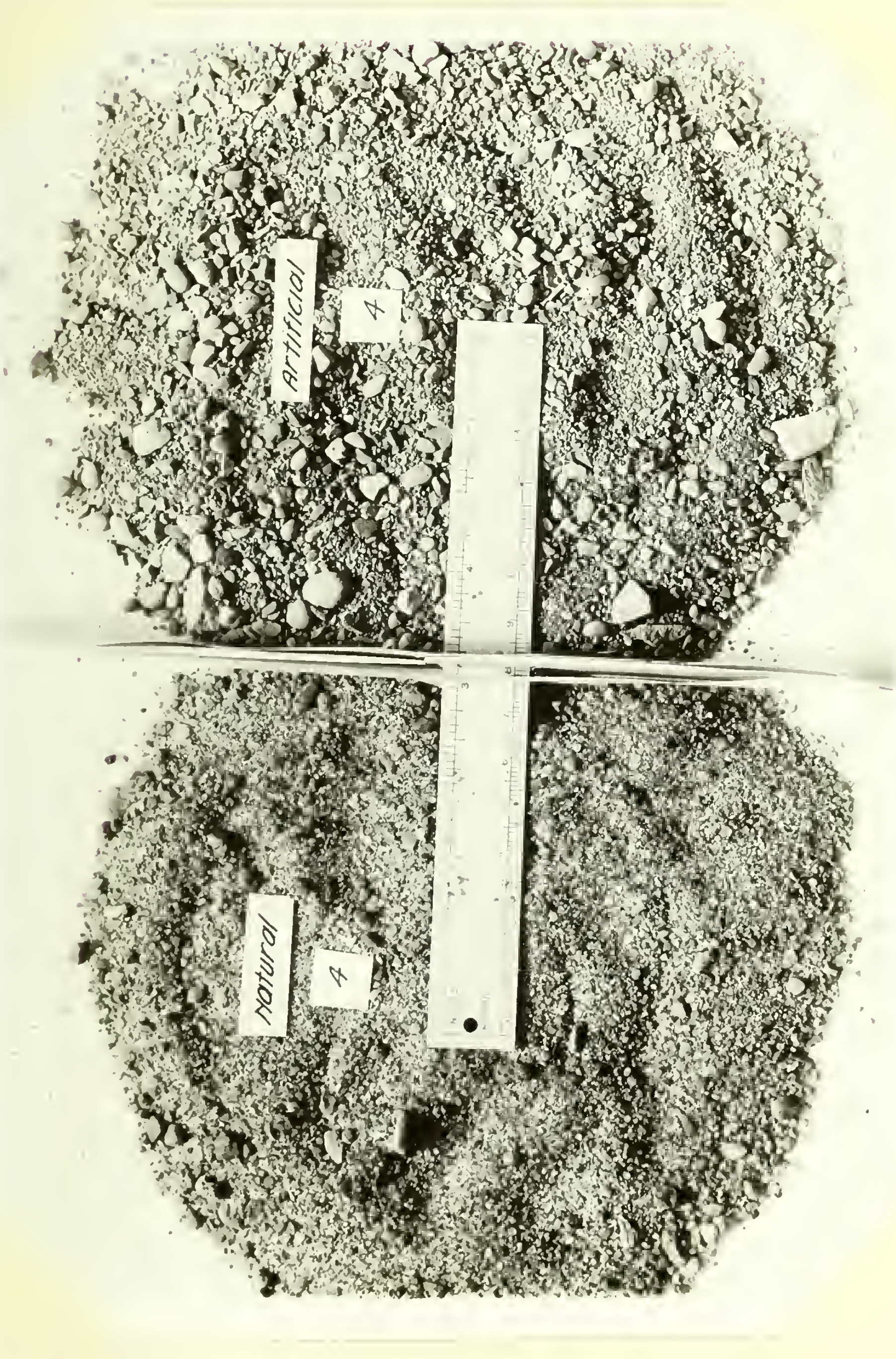
Cylinders in Damp Room - Spray Off

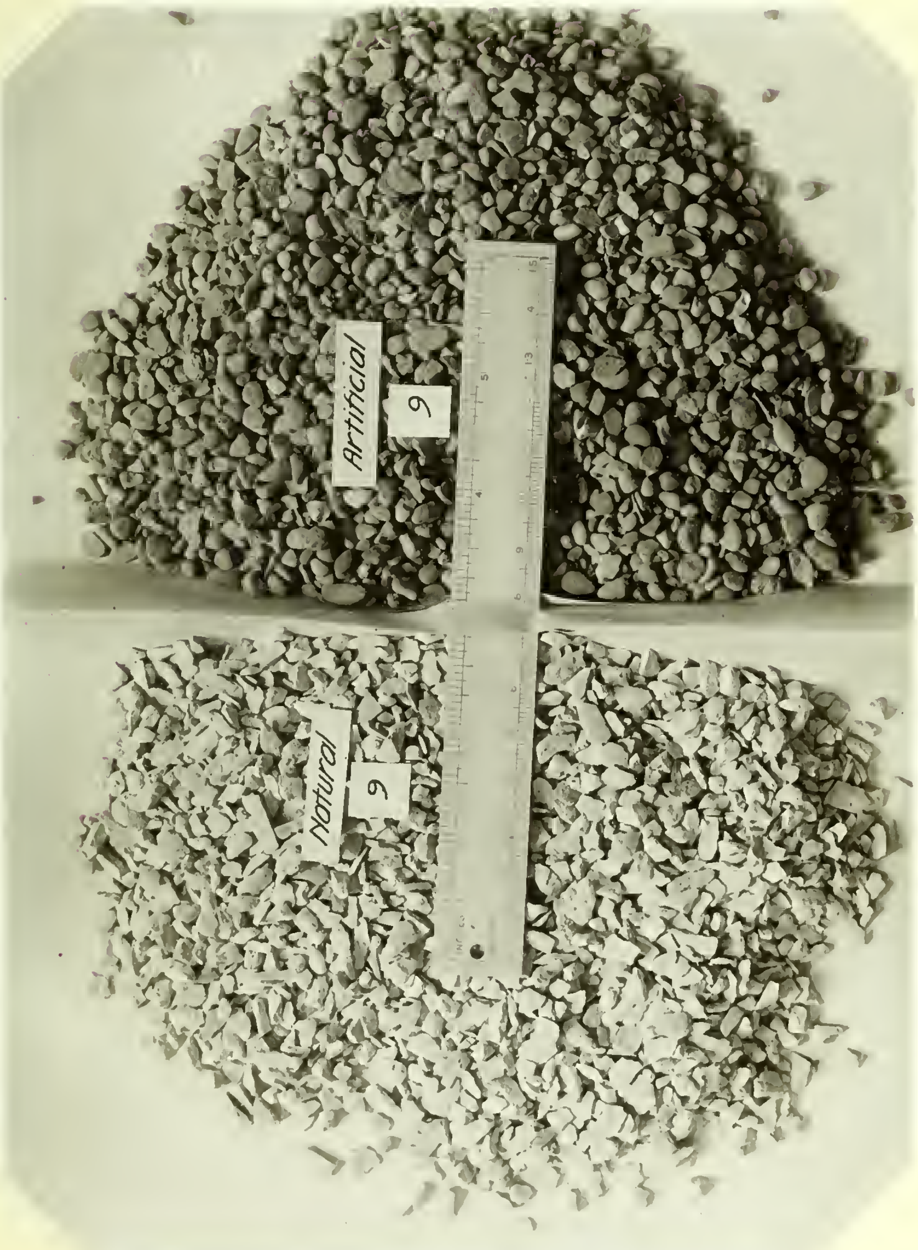
View of Cylinders in Damp Room and Spray in Operation

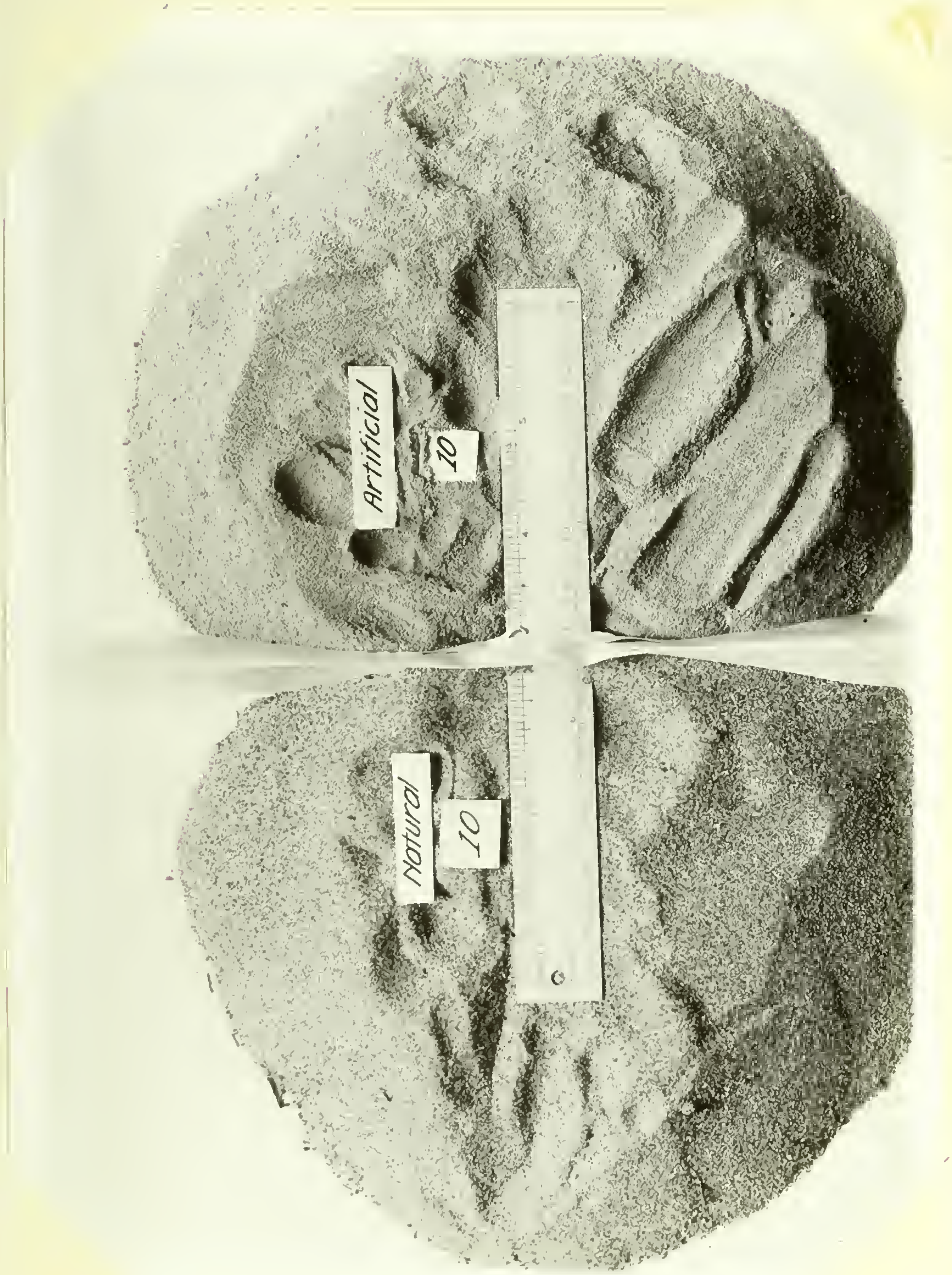
View of a Mix at Basic Water Content on the Flow Table

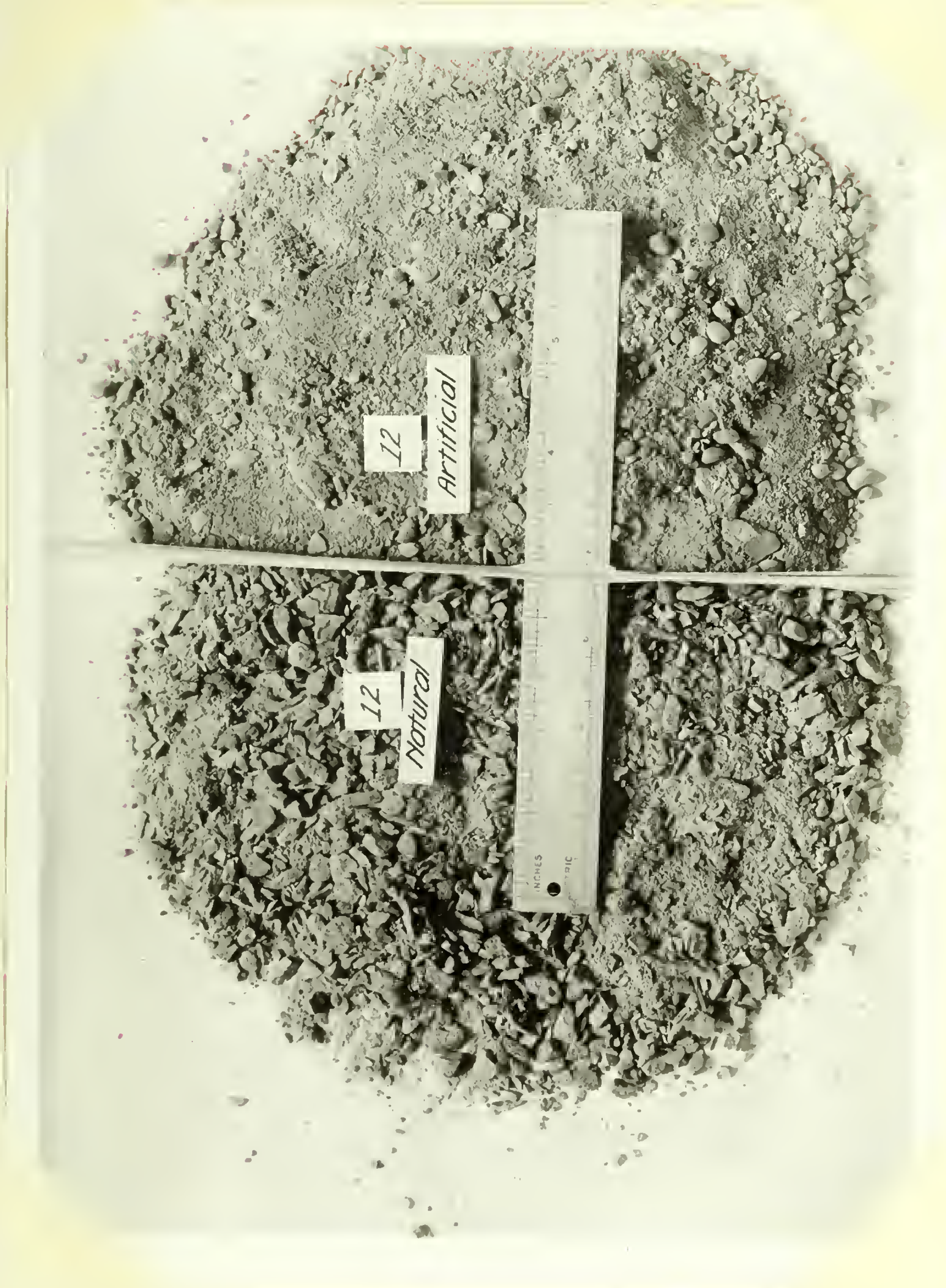
C ncrete of Sand 36 $c = .06$ $b = .45$ $\frac{W_m}{W_{mo}} = 0.84$ 15 drops

Concrete of Sand No. 31 $c = .15$ $b = .40$ $\frac{W_n}{W_{mo}} = 1.30$ 15 drops


Artificial
4
Natural
4


Artificial
9
Natural
9

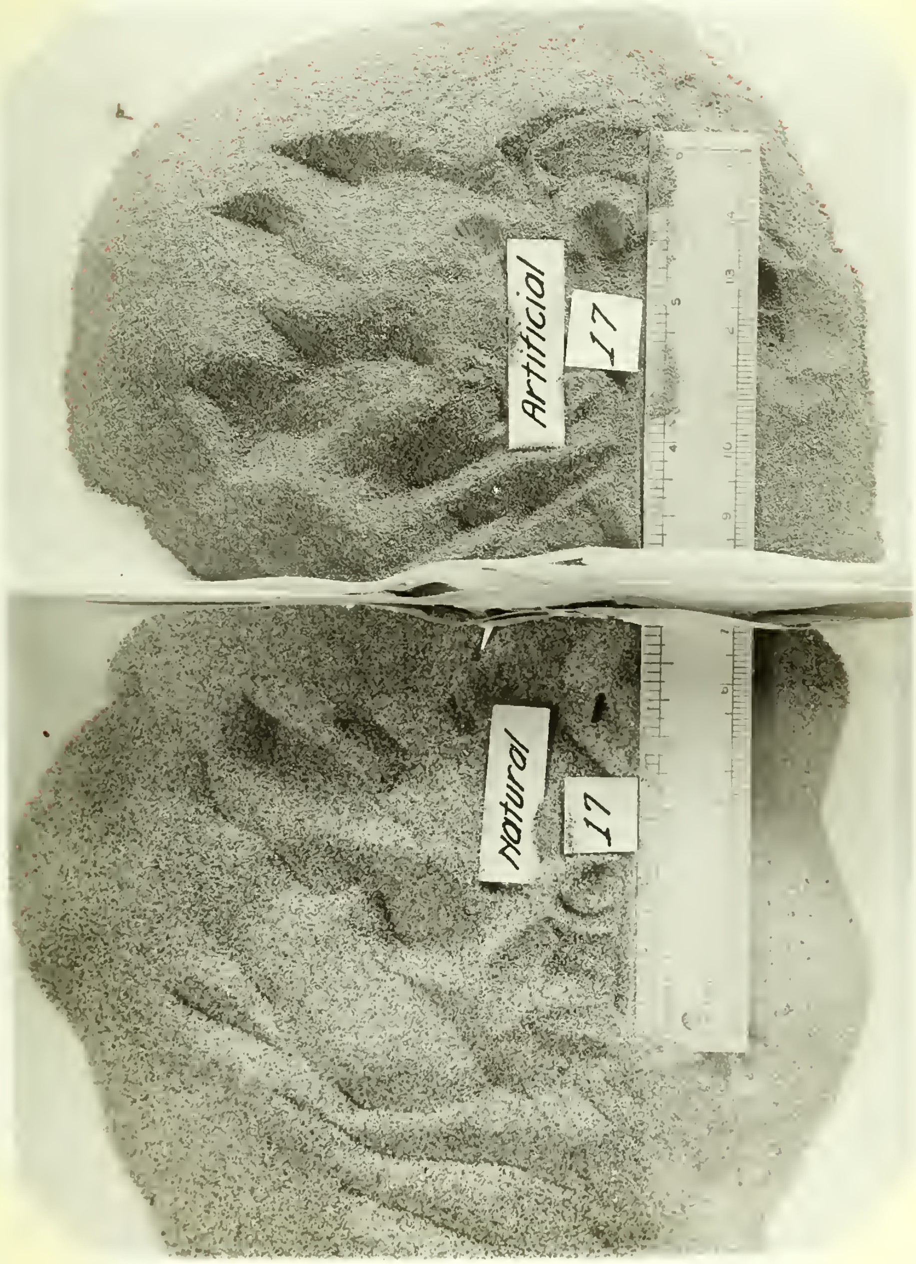

Artificial
10
Natural
10

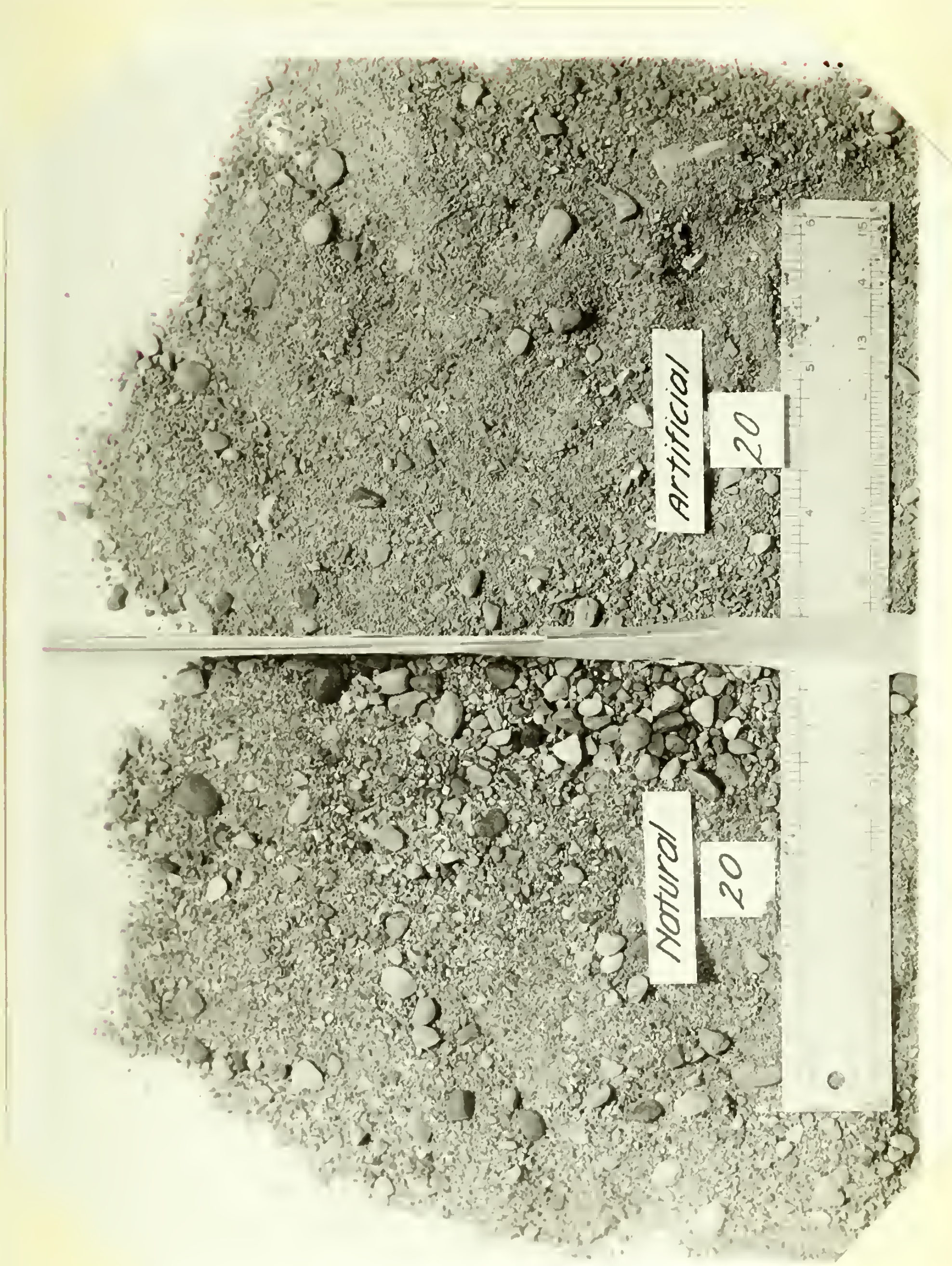

12
Artificial
12
Natural


Artificial
13
Natural
13

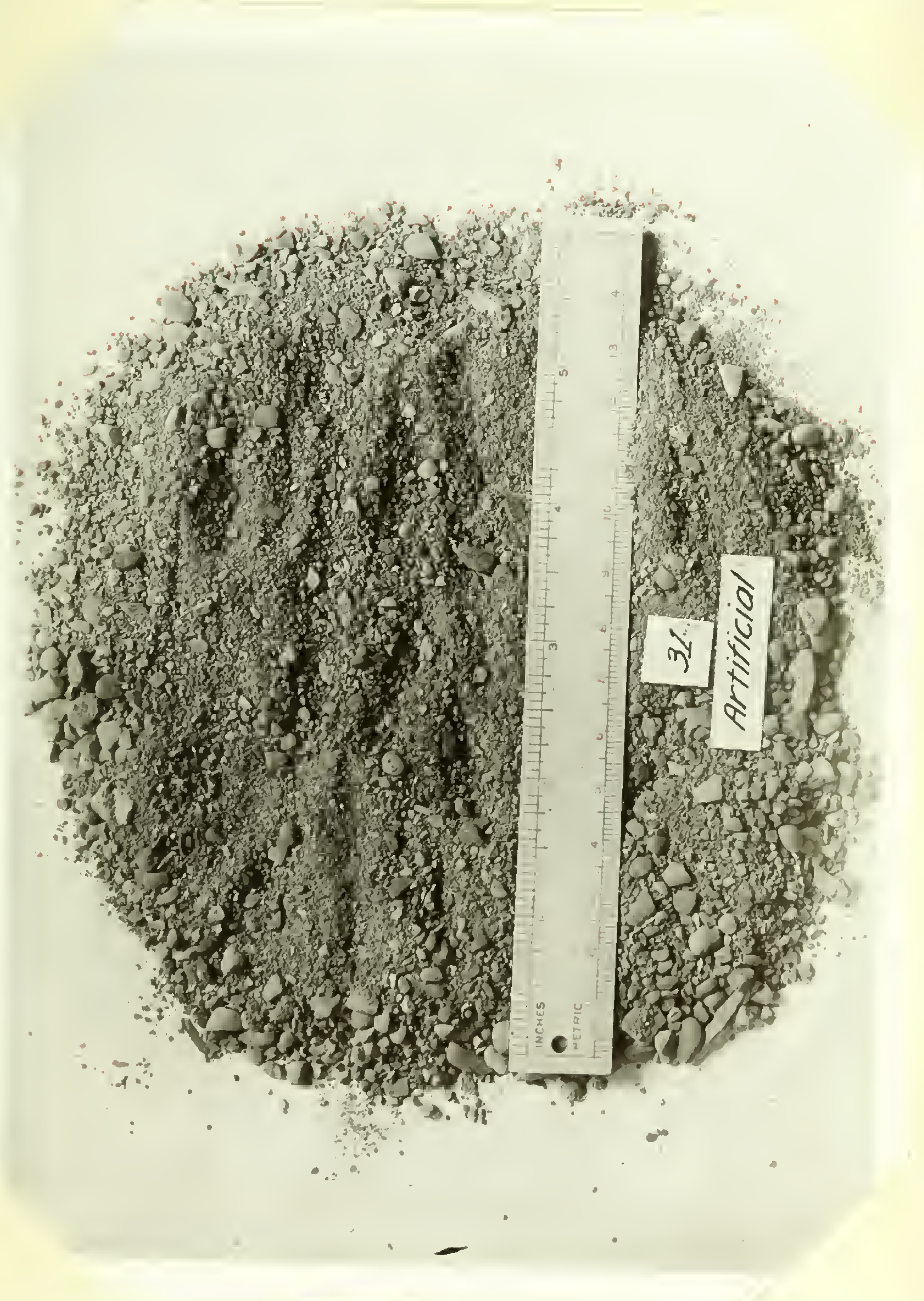

Artificial
14
Natural
14
INCHES
METRIC


Artificial
15
Natural
15


Artificial
17
Natural
17


Artificial
20
Natural
20


Artificial
22
Natural
22


31
Artificial
INCHES
METRIC


32
Artificial


36
Artificial